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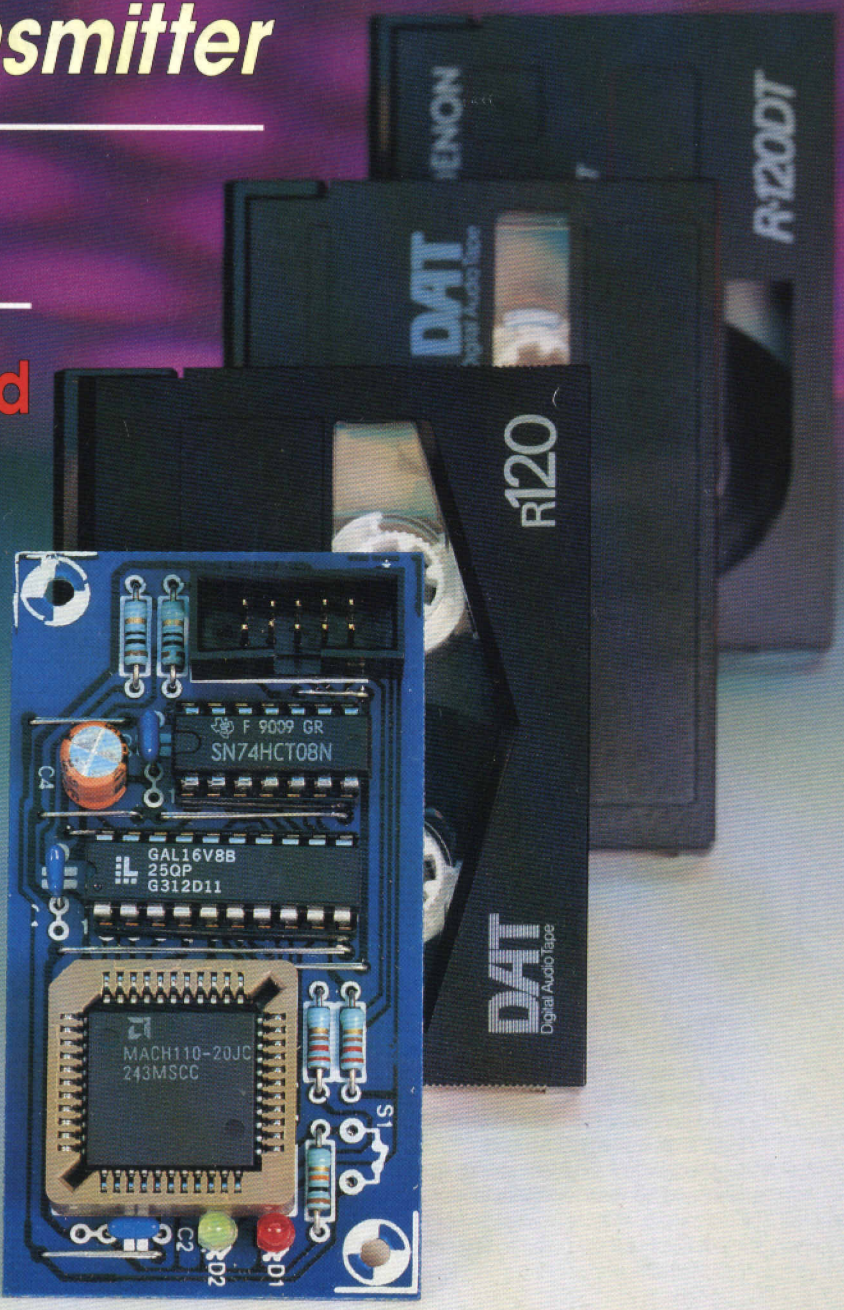

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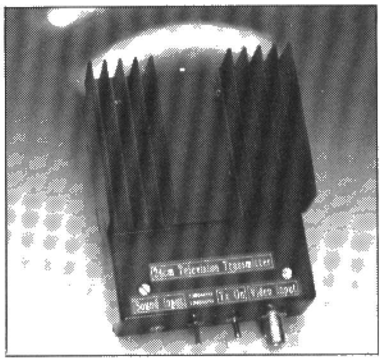

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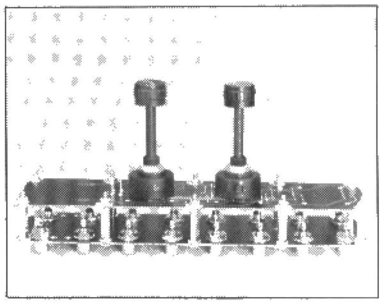

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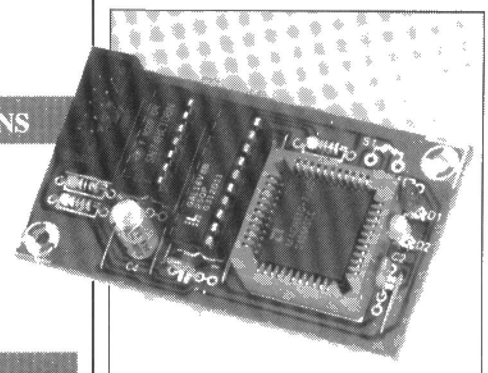

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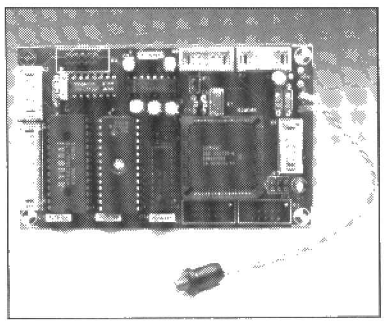

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- PIC programmer
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Front cover
An inexpensive and straightforward circuit for eliminating the copybit from a digital S/PDIF audio signal is described on p.30. It enables any existing or future digital audio source to be copied digitally time after time after time to any other digital audio recording system. It is, of course, intended solely for the digital recording and processing of one's private musical work.

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ALL GAS AND VAPOUR

The development of gas-filled valves

By Gregor M.R. Grant

A century ago this year, two British scientists, the physicist Lord Rayleigh and the chemist Sir William Ramsay, announced their discovery of the gas **argon**. In the following year, Ramsay confirmed the existence of **helium** on earth and, over the next four years with the assistance of the chemist Morris Travers, successfully unveiled the remaining inert gases in the atmosphere: **neon**, **krypton** and **xenon**.

At the century's close, another Briton, the meteorological physicist C.T.R. Wilson, showed that electricity could flow in a gas. Thus, the groundwork was laid for a new branch of the electrical industry: the technology of gas-filled valves.

In 1901, the American inventor Peter Cooper-Hewitt produced a mercury vapour lamp and nine years later the French scientist George Claude developed glass tubes containing a neon-helium mixture. They were some 38 ft (11.58 m) long and the prototypes of the near-infinite variety of such tubes that colour our lives today.

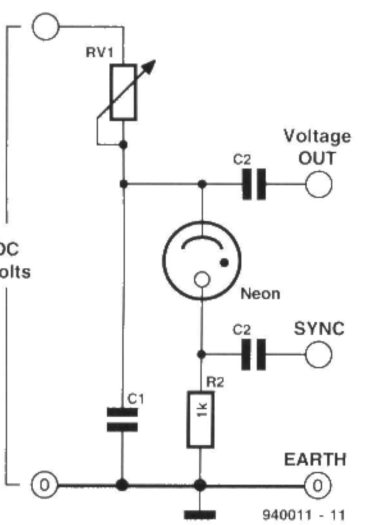

Fig. 1. A simple neon time- base circuit.

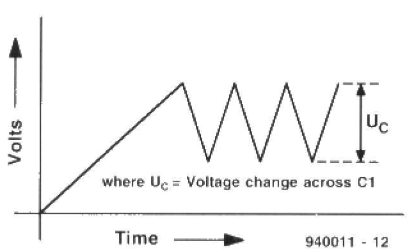

Fig. 2. Time-base voltage amplitude of Fig. 1.

Gas tubes therefore are electron tubes containing vapour or gas at low pressure in which an electric discharge takes place. There are two general types. Firstly , the **cold cathode tube** in which a glow discharge serves to maintain a conducting path between the electrodes. These tubes have a **high** voltage drop and **low** current. **Hot cathode tubes** on the other hand operate on the principle of an arc discharge conducting a current. They have a **low** voltage drop and a **high** current.

By 1914, the American physicist Irving Langmuir began to take an interest in the development of gas-filled, tungsten-filament lamps. The filaments he used were coiled and the space around them contained some mercury, which was allowed to condense and then return to the filament area. Fed from a 110-volt source via a series resistor, they enabled Longmuir and his team to look into the lamp's operation at high temperature. One early observation was that, during the many burn-outs, an arc was created at the filament breakpoint. In the course of these trials, Langmuir became the first scientist or engineer to show '...how a grid voltage could be used to control the starting of the main arc.'[1] In fact, one of Langmuir's team sketched a glass tube with a hot filament, separate anode and liquid mercury cathode, thus anticipating the **mercury arc** rectifier.

The neon tube and the thyratron

By 1922, the British radio engineer R.St.G. Anson developed the relay named after him in which '... a neon tube was used for signal-shaping in telegraph circuits.'[2]

Neon is, of course, one of the two most commonly used inert gases, the other being argon. Industrially, argon is the more often used of the two, largely because the only commercial source of neon is the earth's atmosphere. Indeed, where would our profession be without either argon or – above all – neon?

The neon tube is simply a diode valve filled with low pressure neon gas. Neither of the electrodes is heated, but when a potential is applied across them the gas ionizes. The magnitude of the potential, known as the **striking voltage**, depends on the gas pressure, the material used for the electrodes, and the surface condition and the distance between the electrodes.

For neon, the striking voltage is around 130 V. When this potential falls to about 100 V, however, the gas deionizes. This became the basis of the early time-base circuits. A simple neon time-base is shown in **Fig. 1**. Capacitor C_1 charges up through variable resistor RV_1 and is discharged through the neon tube when the charge equals the tube's striking voltage. Thus, the time base voltage amplitude is the difference between the ionizing and deionizing levels, that is, around 30 V. This is shown in **Fig. 2**.

The time base and the voltage under investigation can be synchronized by applying the voltage across R_2 in series with the neon tube. In other words, a time base is an electronic sun dial which, if combined with a delineating device, gives a graphical indication of electrical phenomena. One such device is the oscilloscope; another, the digital signal analyser.

By 1928, however, the time base was still an unsatisfactory circuit since its output voltage, and hence the amount of deflection it could provide, was small. Matters improved immediately, however, with the introduction of the **gas-filled valve**, or **thyratron**. Its creator, Albert W. Hull, was a versatile and unusual man. He had originally graduated in Greek from Yale and taught languages for a few years before returning to his alma mater to study physics. In 1921, he published a brilliant paper on electron movement between two cylindrical structures in a magnetic field, which configuration he termed a **magnetron**!

It was at this time, too, that he joined the General Electric Corporation's research laboraroty at Schenectady, New York. Here, he followed his earlier work with a paper on

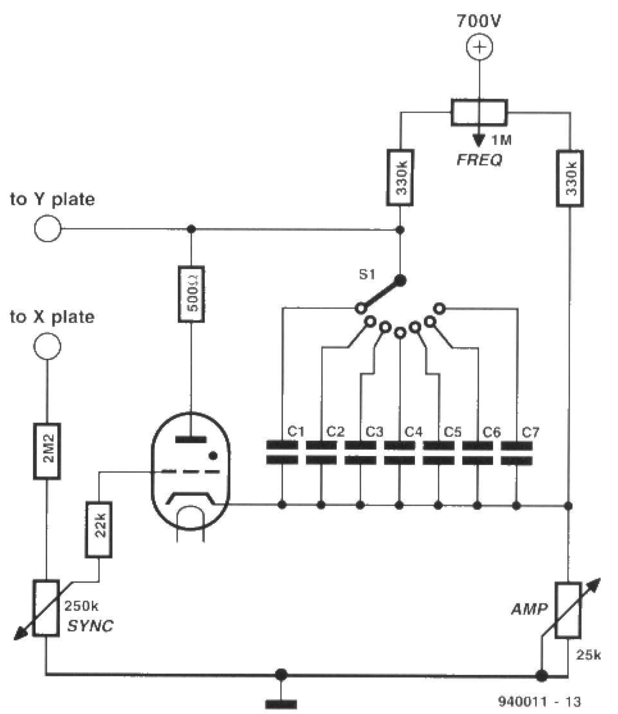

Fig. 3. An AF and low-RF time-base circuit employing a thyratron.

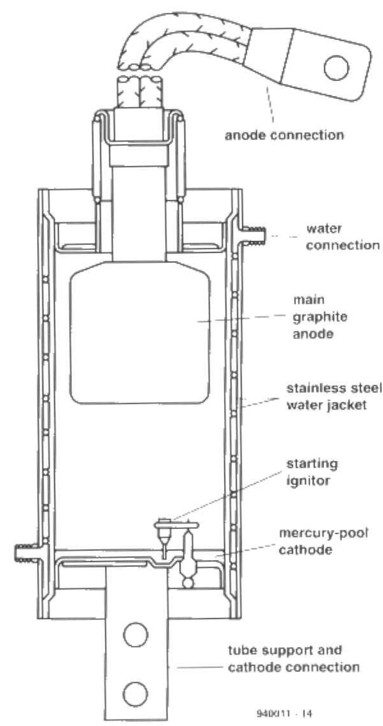

Fig. 4. A typical sealed ignatron.

'Hot Cathode Thyratrons' in 1928, announcing the device itself and, in 1933, his masterpiece, 'Thyratrons'.

Basically, the device was a thermionic valve '... filled at very low pressure with mercury vapour or one of the inert gases ... the characteristics of the valves being to some extent influenced by the particular gas filling.'[3] These devices gave renewed impetus to the use of the cathode ray oscilloscope as an investigative tool '... because they pass negligible current until a certain voltage ... is reached, when they suddenly conduct very freely, indeed'[4], discharging a capacitor with considerable speed, thus producing a rapid flyback. This last was the result of '...an increase in the separation between the **striking** and **extinction** potentials.'[5]

Shortly after the thyratron's introduction, the leading engineers of the day, among them Alan Blumlein, designed time-base circuits around it. Blumlein's 1932 British-patented design used a large inductor in the charging circuit to improve charge linearity.

The frequency range of the thyratron, however, was not all that extensive and they proved, ultimately, to be less effective as time-base generators than hard valves, firstly because of their relatively short life, and secondly because of their inconsistent characteristics.

Blumlein was the man who first used the **Miller effect** of a triode valve to create the first truly linear time base. He developed it in the early 1940s whilst working on an airborne radar system and termed it the **Miller integrator**.

Another serious limitation of thyratron-based time-base circuits was their recovery time from the flyback condition. This took '... a serious fraction of the cycle at a few tens of kHz'[6] and so limited their effective frequency range. In fact, by the late 1950s thyratrons were no longer used in commercial oscilloscopes. **Figure 3** is a good example of a thyratron-based time-base circuit.

The ignatron

In 1933, the Westinghouse Corporation announced their latest development, the **ignatron**, whose general construction is shown in **Fig. 4**. A pool of mercury serves as the cathode. Its potential was quickly appreciated and by the end of the following year a welding control system using such devices was in commercial operation in the USA.

In welding operations the ignatron acts '... as a special form of timing switch, enabling a current to pass through the metal junction for a specified and controlled period.'[7]

The ignatron combines many of the features of the mercury arc rectifier with those

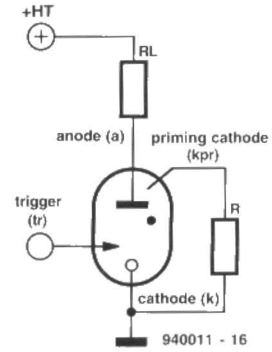

Fig. 6. Circuit operation of the Z700U cold cathode trigger tube.

of the thyratron. Like the latter, the ignatron has a low arc voltage drop, but one combined with a far larger current than can be achieved with a thermal cathode of the type used in a thyratron.

In the welding circuit of **Fig. 5**, both ignatrons and their protective resistances are shunted by metal rectifiers to prevent reverse current passing through them. At switch-on, ignatron 1 anode is positive. Consequently, current flows from the anode to the cathode of ignatron 2, where it divides, the larger part passing through rectifier D_2, the remainder flowing through Ig_2 and R_2 as reverse current. The major portion then continues through fuse F_2, the timing circuit, the water-flow switch and fuse F_1, where it again divides, the larger part passing through R_1 and the ignatron igniter. Thus, Ig_1's igniter handles a large current pulse which fires the main discharge. Immediately the discharge is set up, the igniter is short-circuited, so that its current is zero.

With the anode of Ig_2 positive, the circuit action is as before, but in the opposite direction. Consequently, each device fires in turn as long as the control circuit is closed. Large current pulses, alternating in direction, flow

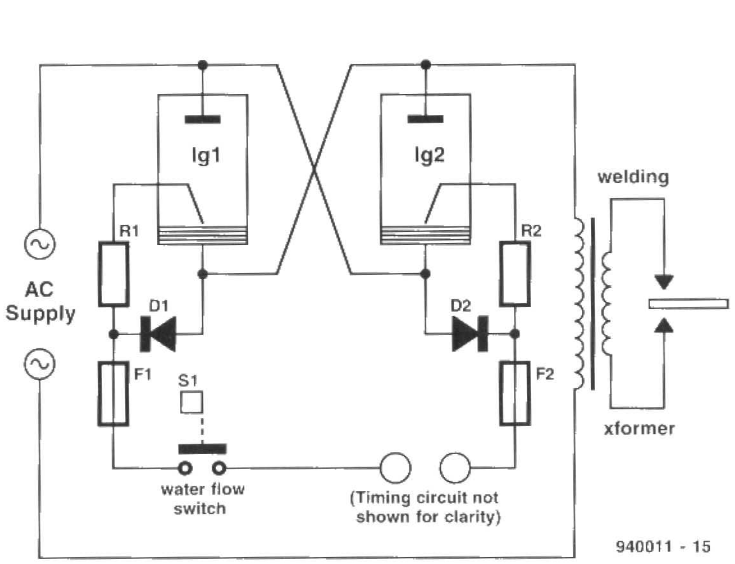

Fig. 5. Ignatron circuit as used in spot welding.

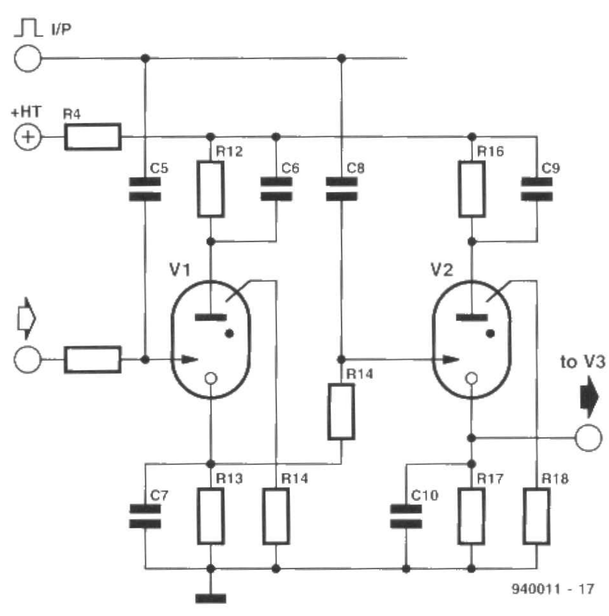

Fig. 7. Part of the ring counter circuit of an early computer.

through the welding transformer primary, inducing even larger ones in the secondary.

The circuit is a typical example of a non-synchronous arrangement used in both spot and projection welding.

The cold cathode trigger tube

In 1936, the Bell Telephone Laboratories announced their latest development, the **cold cathode trigger tube**, an invention of research engineer S.B. Ingram. A later example of the device, the Z700U, is shown in **Fig. 6**.

The voltage applied between the anode and cathode is some 200 V. The **priming cathode**, located behind the anode, is connected to the negative line via current-limiting resistor R. Since the physical gap between the priming cathode and the anode is small, breakdown occurs and a current-limiting discharge develops. Consequently, limited ionization takes place.

The trigger electrode is now made positive with respect to the cathode, causing a discharge across the cathode-trigger gap. This, in turn, increases the ionization, which reduces the anode-cathode gap striking voltage. The anode-cathode gap breaks down, but the discharge within it is maintained. The anode current is limited by R_L, and the cathode-anode voltage remains constant at the tube's maintaining voltage.

When the tube conducts, the trigger is redundant. The tube's glow, therefore, can be extinguished in only two ways: firstly, by reducing the anode current, and secondly by bringing the anode voltage below the maintaining voltage. As can be seen, the device has some facets in common with both the thyratron and the ignatron.

Known as **grid glow tubes** in the UK, they were little used prior to the second world war. Once hostilities had broken out, however, the demand for triggering devices for proximity fuses for bombs, torpedoes, and the like, increased almost exponentially. The cold cathode trigger came into its own. Later, when hostilities had ceased, the tube found another role. It was frequently used in the ring counter circuits in early computers, an example of which is shown in **Fig. 7**.

By the middle of the 1950s, the first commercial **thyristor** or **silicon-controlled rectifier** (**SCR**) was developed by the General Electric Corporation. A decade later it had eclipsed soft valves in many power control applications. Nevertheless, gas-filled valves continue to be used in the very-high-power field.

Currently, the choice of gas depends on the hold-off voltage, current handling and rate of rise of current or turn-on time. Mercury and xenon, for example, are used where high currents are a priority, and hydrogen is the preferred gas for high-voltage applications. Hydrogen thyratrons, in fact, operate at gas pressures of between 300 and 900 millibar and have **very rapid** turn-on times. They can handle stand-off voltages of 50 kV and peak currents of around 5 kA. Among their many applications is high-power laser switching.

Of course, neon, the original soft-valve gas, is still very much with us, its orange-red glow indicating all manner of reassuring parameters from heartbeats to hertzs, Classic FM* to miles per hour.

In their centenary year, however, the inert gases are facing their greatest challenge: semiconductors. SCRs, LCDs and microscopic laser devices already indicate the way ahead. By the turn of the century, soft valves may have joined their hard counterparts as interesting relics of a past technology.

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6. Ibid Ref. 4, p. 161.
7. Ibid Ref. 3, p. 151.

* Classic FM is a chain of radio stations in the UK, broadcasting classical music 24 hours per day, seven days a week.

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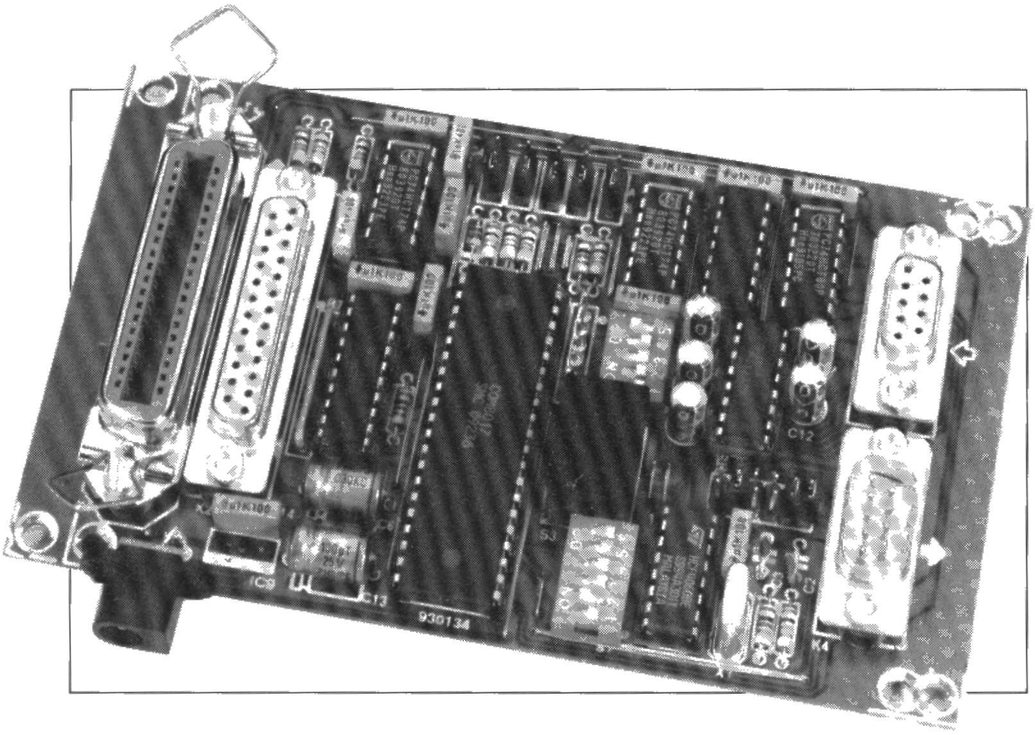
BIDIRECTIONAL RS232-TO-CENTRONICS CONVERTER



The link between a PC and its peripherals is usually either parallel (Centronics) or serial (RS232). In some cases, however, it is necessary to connect the PC's parallel port to a peripheral with a serial input, or the other way around (serial output to parallel input). No problem with the data format converter described here.

Design by A. Rietjens

ADMITTEDLY the demand for parallel-to-serial converters is not as high as it used to be, now that PCs are equipped with a host of peripheral connection options. None the less, there are occasions when such a converter is very useful. Take, for example, the following situation: you are using a number of programs that default to the first Centronics port to produce hard copy, while printer port redirection using the MODE command is either not supported, or difficult to achieve. Unfortunately, the printer is in the room next door, and the distance is such that serial communication is likely to be more reliable than parallel communication. Another example would be a printer with a Centronics input only, which you would like to connect to a serial cable.

The converter described here can work in two directions: parallel to serial, or serial to parallel. Unfortunately, these conversions can not operate simultaneously, but that will rarely cause problems.

Block diagrams

Since the present circuit is bidirectional (the direction being set with the aid of jumpers), it is appropriate to give separate block diagrams for the two directions of conversion. These diagrams are shown in **Fig. 1**.

Before describing the general structure of the circuit, a short discussion on the protocols drawn up for communication via the Centronics and the RS232 ports on a PC. The Centronics standard is based on eight databits which are conveyed in parallel. The sending device signals the presence of valid and stable data by pulling the STROBE line logic low. The receiving device has two ways of signalling its state. By transmitting a BUSY signal, it can inform the sending device that it is busy, and can not handle new data at that particular moment. The acknowledge signal, which is active low, and usually appears at the end of the BUSY signal, is sent by the receiving device to signal that a databyte has been received correctly for processing. Since BUSY and ACKNOWLEDGE have roughly the same function, many printers supply a BUSY signal only (although an ACK connection is available as a secondary function).

An RS232 link has a serial data input and output at both ends. In addition to data lines, it has several control lines, which allow a number of different modes of communication (handshaking) to be implemented between two devices. One of these is the XON/OFF handshaking protocol, when the receiver transmits a certain character via the serial data line to tell the sending device to continue or stop transmitting data. Most printers, however, employ hardware handshaking. A line called DTR (data terminal ready) is actuated by the printer to signal that it is ready to receive data. Since the transmission of serial bits is stopped as soon as DTR is de-actuated, the function of this line may be compared with that of BUSY on the Centronics port. Another possibility is the RTS (request to send) line. An active level on this line indicates that the receiver wants to receive data, or is ready to do so.

Armed with a basic knowledge about the function of the main signals we can start to examine the operation of the converter circuit. Referring to **Fig. 1a**, when parallel-to-serial conversion is used, data enters the circuit via the Centronics converter, and is stored in a buffer (actually a latch) under the control of the STROBE signal furnished by the sending device. A special integrated circuit which contains a parallel-to-serial converter and a latch ensures that the eight received data bits are shifted sequentially, in the correct order. The sequence of eight data bits is preceded by a start bit, and followed by a stop and/or a parity bit. The block marked 'handshake' arranges the communication between the two sides. The busy and acknowledge signals needed for this purpose are derived from the DTR or the RTS control signal supplied by the RS232 sending device. The selection

between DTR and RTS is made by the user.

The diagram of the serial to parallel converter (**Fig. 1b**) is virtually the mirror image of its parallel-to-serial counterpart. Serial data arriving at the circuit are converted into parallel, with the converter using the CTS (clear to send) line to signal to the sending device that bits may be transmitted. When a complete serial word is received, the seven or eight databits contained therein are conveyed, in parallel, to a latch. Next, a strobe pulse is issued to tell the equipment connected to the Centronics output that valid and stable data are available for copying. At the same time, the handshake logic looks at the state of the BUSY line, to see if new data may be transmitted. **Figure 1b** also shows feedback between the converter's output and input. This has been added because many RS232 ICs in PCs appear to have a buffer of two bytes. This means that the transmission of the current byte is not stopped immediately on receipt of a 'halt' condition, but the buffer is cleared first. Consequently, the converter receives another byte, although it has told the sending device to stop transmitting. This extra byte has to be stored, because the Centronics device is not (yet) ready to accept it. The feedback causes the extra byte to circulate in the converter until the Centronics bus is freed again.

So far, so good. Although the blocks in the diagrams in **Fig. 1** would appear to cover all function of the circuit, the handshake signals do require a couple of discrete gates and bistables to be added.

Circuit description

The heart of the circuit shown in **Fig. 2** is the Type COM8017 UART (universal asynchronous receiver/transmitter), which is a follow-up type of the now obsolete AY-3-105D. The COM8017 arranges the conversion from parallel to serial and vice versa. These operations run under the control of a clock signal supplied by IC_2, a CD4060. The clock generator/divider uses a 2.4576-MHz quartz crystal. The dividers contained in the CD4060 provide the TCP and RCP (transmitter and receiver clock) signals for the UART. The frequency of these signals must equal 16 times the desired baud rate, and can be selected wit the aid of a DIP switch block, which connects one of IC_2's outputs Q3-Q8 to the UART clock inputs.

Another DIP switch block, S_2, allows the format of the serial words to be set. The parameters are the number of databits, the number of stop bits, parity bit yes/no, and odd or even parity. The function of each switch in the DIP block is shown in **Table 1**.

The parallel data enter the circuit via Centronics connector K_1, and are fed to a bidirectional databus buffer, IC1. Depending on the logic level applied to pin 1, this buffer copies the data at the Centronics input to the COM8017, or the other way around. At

MAIN SPECIFICATIONS

- Conversion from parallel to serial, or serial to parallel (not simultaneously).
- Busy and acknowledge signal available for parallel input.
- Serial output programmable for crossed and non-crossed cable (or DTE/DCE selection).
- Selection between RTS and DTR on serial output.
- Available baud rates: 9,600; 4,800; 2,400; 1,200, 600 and 300.
- Serial data format fully configurable: number of data bits, parity bit, odd/even parity; number of stop bits.
- On-board RS232 voltage level converter.

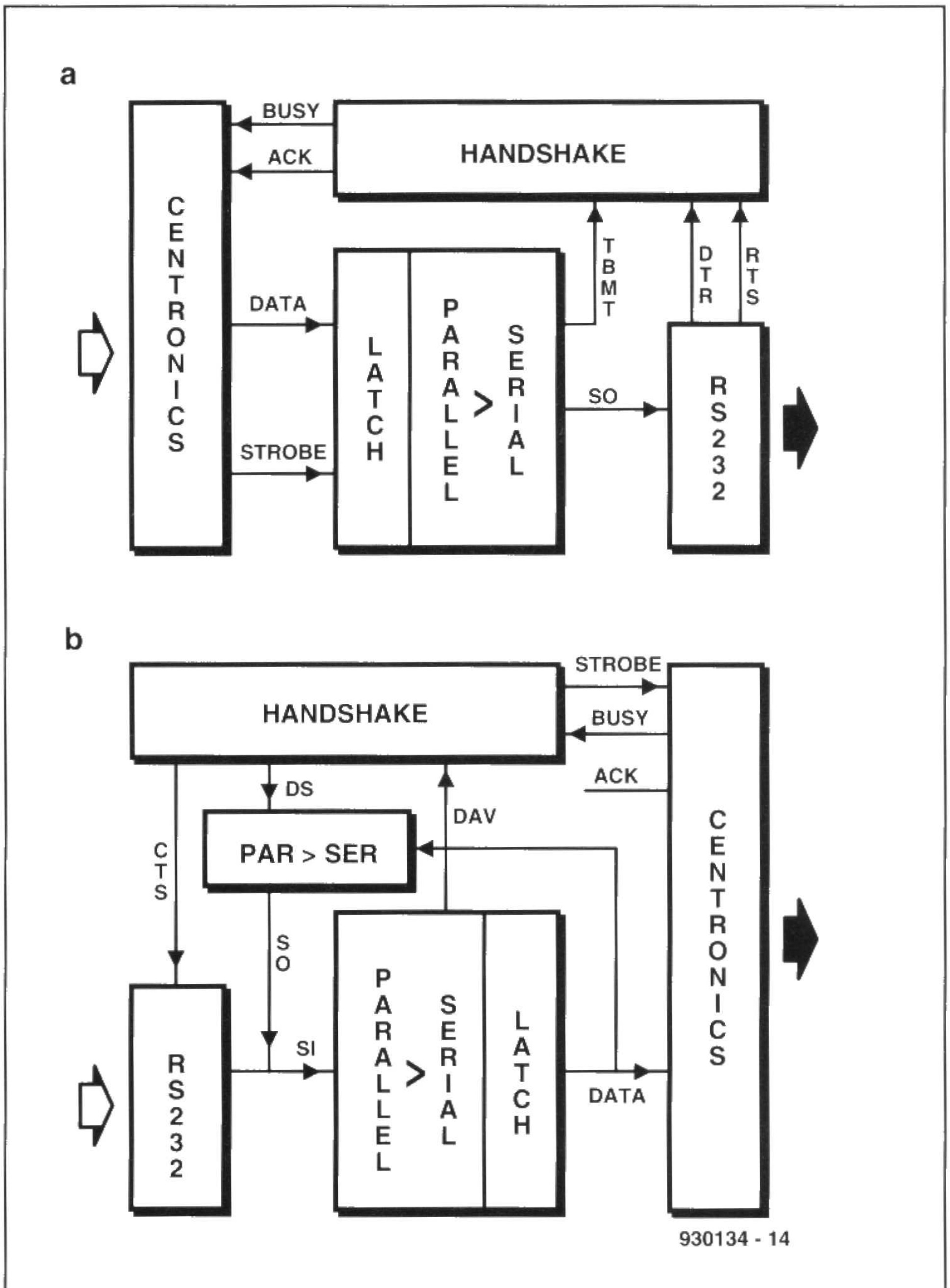


Fig. 1. Two block diagrams for a single circuit with two functions. One (a) for parallel-to-serial conversion, and one (b) for serial-to-parallel conversion.

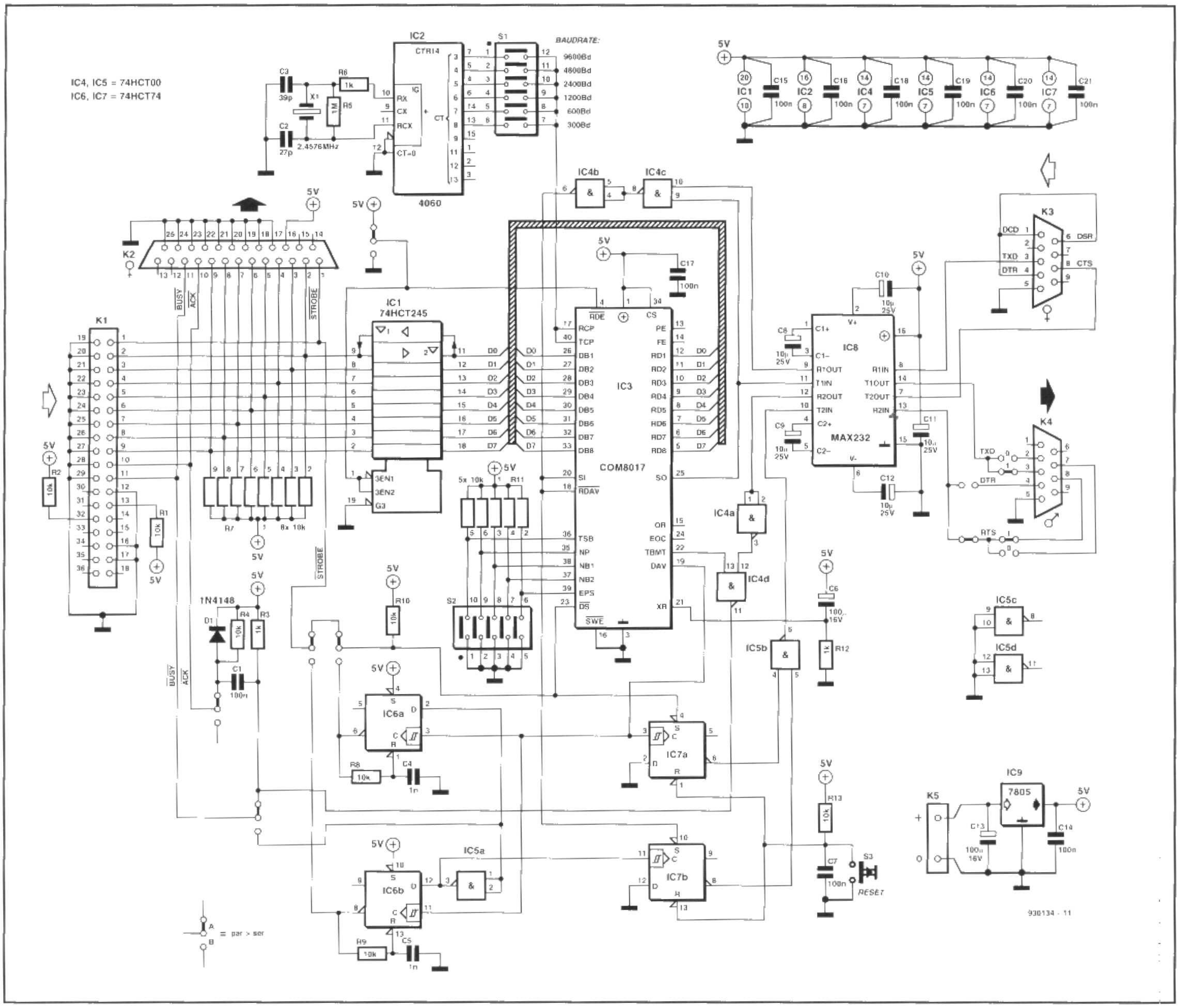


Fig. 2. The heart of the circuit is formed by IC3, a COM8017, which takes care of the data format conversion in both directions (not simultaneously, though).

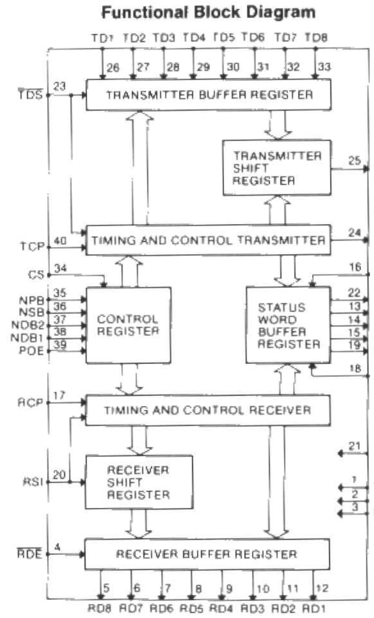
the other side of the circuit, a special IC is inserted between the serial input and output of the COM8017 to take care of the logic level conversion between the 5-V logic in the converter circuit and the RS232 lines (which carry symmetrical signals with a swing between ±5 V and ±15 V). The special IC is a MAX232, which contains a combination of voltage doublers and current-to-voltage converters. Outputs T1out and T2out supply signals with a swing of about ±10 V. Signals received via the RS232 connectors are applied to the R1in and R2in inputs (pins 8 and 13) and converted into asymmetrical 5-V levels.

When the parallel-to-serial conversion is done, the serial data is available on pin 25 of IC_3 (SO). After conversion by IC_8, the data then travel to the TxD or RxD pin of connector K_4. The selection between these two pins is made with the aid of a jumper, and

UART COM8017

The COM8017 from Standard Microsystems Corp. is a 40-pin integrated circuit with a strong resemblance to the familiar AY-3-1015 (produced by General Instruments Corp., and now obsolete). The COM8017 contains all logic needed to convert parallel data into serial, and vice versa. The block diagram shows the structure of the IC, which contains an input/output buffer and associated shift register, two blocks of logic that serve to arrange the flow of data traffic, a control register and a status register. Although the structure of the IC allows simultaneous two-direction data traffic (full or half-duplex using two virtually separate 'channels'), this feature is not used in the present circuit, since situations requiring simultaneous data format conversion are few and far between.

Functional Block Diagram



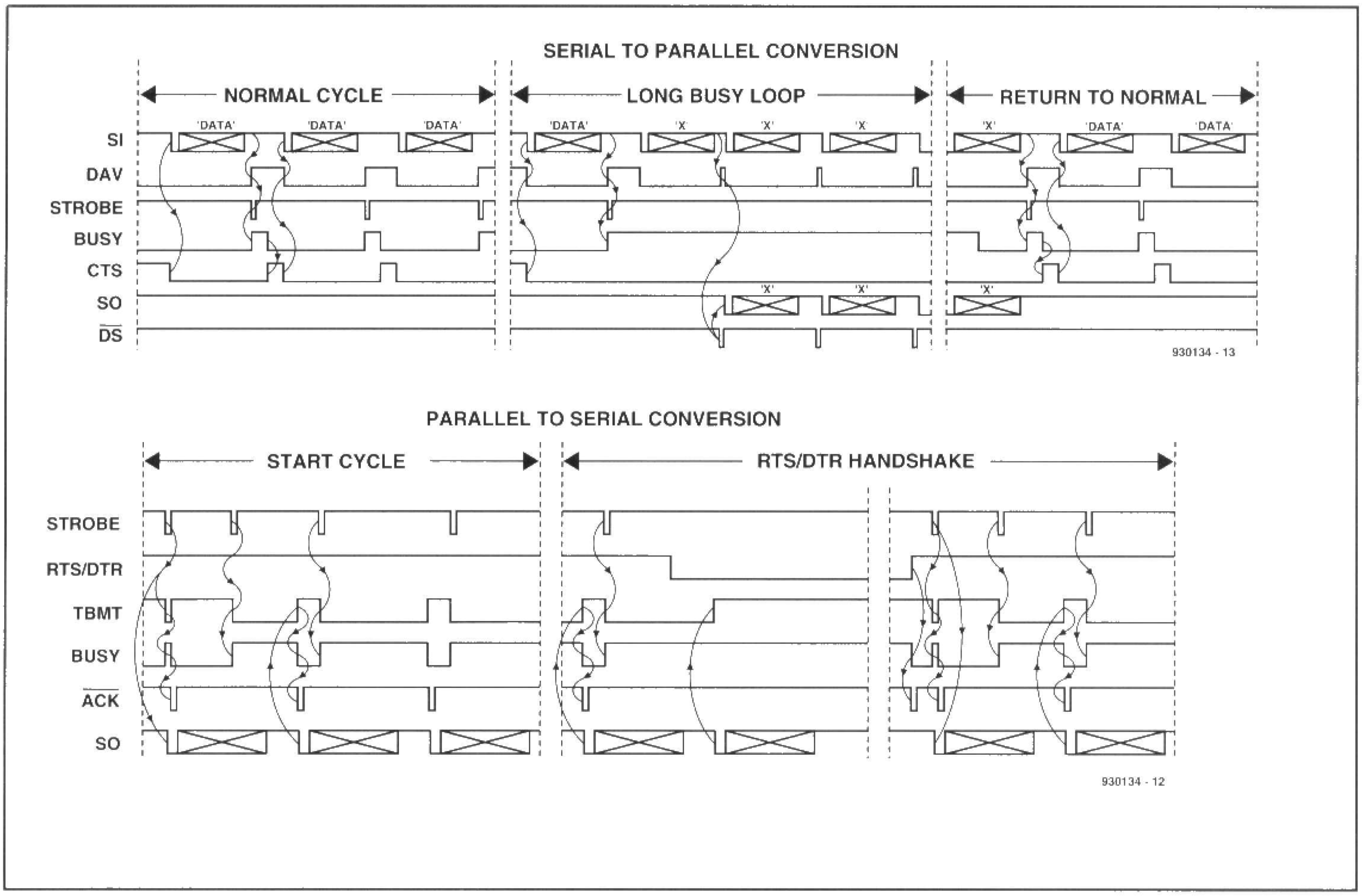


Fig. 3. These timing diagrams should help to elucidate the rather complex operation of the circuit.

depends on the type of serial cable applied, and the type of equipment connected. The position '1' jumpers will typically be fitted near the RS232 connector when the equipment is of the DCE type, while position '2' is used with DTE types, which includes most printers. The options for handshaking with the serial equipment are DTR and RTS. Select one of these in accordance with the requirements of the equipment you wish to connect. The user manual will usually provide this information.

Serial data to be converted into parallel are applied to the converter via connector K_3. In this mode, the converter behaves like DCE (data communication equipment), which is based on the assumption that a computer is connected. After the level conversion in IC_8, the data travel to the serial input of IC_3 (pin 20). The parallel data available after the conversion is fed out to outputs RD1-RD8. This byte is then conveyed to connector K_2 via buffer IC_1. K_2 then forms the Centronics output of the converter, and may be used to hook up a printer with a standard Centronics input. The feedback loop indicated in the block diagram is realised by a simple connection between the output buffer (RD1-RD8) and the input buffer (DB1-DB9) of IC_3.

Handshaking

The circuit diagram shows a number of jumpers that can be fitted in two positions. With the jumpers fitted as shown in the circuit diagram, the converter functions as a parallel-to-serial converter. Signals 'busy' and 'acknowledge' enable the converter to provide its current state information to the equipment connected to K_1. The busy signal is fairly simple to generate. RTS or DTR is active on K_4 if the serial equipment is ready to receive data. If the TMBT output of IC_3 is also high (transmitter buffer empty), NAND IC_4 pulls the busy line logic low. This level is also used to enable a small network, D_1-C_1-R_3-R_4, to derive the acknowledge (ACK) pulse, which appears as a logic 0 after the negative-going edge of the busy signal. The 0 indicates that the converter has received and processed data. Next, if new data appears on the Centronics bus, the equipment connected to K_1 will supply a strobe pulse to signal that valid data is available for loading into the converter. This pulse is fed to the DS input of IC_3, which responds by loading the data into its input buffer. Next, the data is converted into serial format, and conveyed to the RS232 receiver. During the conversion, TBMT is low (and, consequently, busy is high), which means that the converter is not ready to receive new data. Once the serial data converter is no longer capable of handling the incoming datastream, it pulls DTR or RTS low, which also results in a 'high' busy line.

The other way around is 'serial-in, parallel-out'. A jumper is used to reverse the direction of buffer IC_1 (via the logic level applied to pin 1). The acknowledge signal is disconnected from K_1. The strobe line is turned into an input, and the busy line into an output.

As soon as IC_3 detects a negative-going pulse transition (falling edge) at its serial input (caused by data arriving from K_3), the IC first checks if this is a start pulse by measuring the length of the pulse. The falling edge also pulls the DAV (data available) output of the COM8017 low. This is achieved with the aid of the RDAV\ input. Also, S-R (set-reset) bistable IC_{7b} is set, which is done to inform the serial transmitter, via the CTS line, to stop transmitting after the current byte. After the conversion, the parallel data are available in the output buffer (provided the 'old' data were sent correctly). The presence of this new data is indicated by the DAV output going high. The DAV output clocks bistables IC_{6a}, IC_{6b} and IC_{7a}. Two *RC* networks, R_8-C_4 and R_9-C_5, turn the two bista-

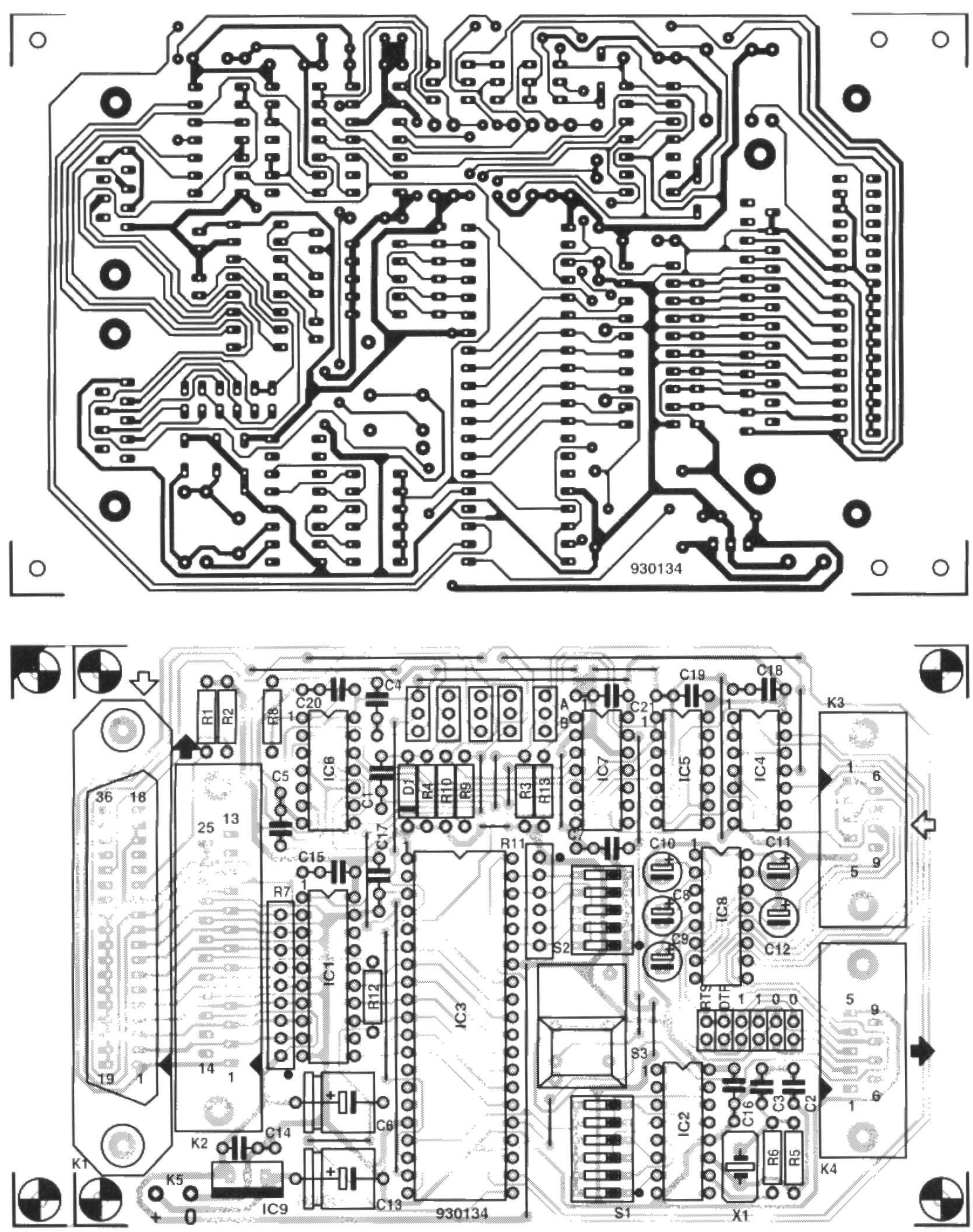


Fig. 4. Track layout and component mounting plan of the printed circuit board designed for the converter.

bles in IC_6 into a monostable. If the equipment connected to K_2 is not busy, IC_{6b} will generate a strobe pulse, and the available data is copied to the Centronics equipment connected to the converter. Next, IC_{7a} and IC_{7b} ensure that the RS232 transmitter is informed, via the CTS line, that new data may be transmitted. If the busy line was still high, the D input of IC_{6b} is held at 0, and no strobe pulse is generated. IC_{6a} applies a pulse to the DS input of IC_3. This causes the received byte to be sent from the serial output to the serial input via IC_{4b} and IC_{4c}. At the end of this sequence, a DAV signal is generated to ensure that the byte is 'circulated' again if the receiver is still busy. Else, a strobe pulse is generated for the receiver.

Finally, the circuit has a reset key, S_3, which is useful when the communication stalls owing to a transmission fault. Pressing this key results in IC_{7a} and IC_{7b} being reset.

The circuit is best powered by an external mains adaptor with an output voltage of 8-15 V d.c. Regulator IC_9 provides the 5-V supply voltage for the circuit. The current consumption of the converter is about 100 mA.

Construction

The printed circuit board for the converter (**Fig. 4**) is designed such that all components are accommodated on a single board. The parallel input and output connectors are located at one side of the board, while the serial connectors are arranged side-by-side on the other side. All connectors are types with straight solder pins to enable the cables to be connected from the top side of the board. Fitting the parts on to the board should not present problems. IC sockets may be used if you are less confident of your soldering skills. The reset press-key is also fitted directly on to the board. The completed board fits exactly into the enclosure mentioned in the parts list, although clearances have to be cut for the four connectors, the two DIP switches, the press-key and the mains adaptor socket. If you use the enclosure mentioned in the parts list, the voltage reg-

COMPONENTS LIST

Resistors:
R1;R2;R4;R8;R9;R10;R13 = 10kΩ
R3;R6;R12 = 1kΩ
R5 = 1MΩ
R7 = 8-way 10kΩ SIL array
R11 = 5-way 10kΩ SIL array

Capacitors:
C1;C7;C14-C21 = 100nF
C2 = 27pF
C3 = 39pF
C4;C5 = 1nF
C6;C13 = 100µF 16V
C8-C12 = 10µF 25V radial

Semiconductors:
D1 = 1N4148
IC1 = 74HCT245
IC2 = 4060
IC3 = COM8017
IC4;IC5 = 74HCT00
IC6;IC7 = 74HCT74
IC8 = MAX232
IC9 = 7805

Miscellaneous:
K1 = 36-way Centronics socket; PCB mount; straight pins
K2 = 25-way sub-D socket; PCB mount; straight pins
K3 = 9-way sub-D socket; PCB mount; straight pins
K4 = 9-way sub-D plug; PCB mount; straight pins
K5 = two solder pins
S1 = 6-way DIP switch
S2 = 5-way DIP switch
S3 = Digitast press-key, 12 mm wide cap (ITT/Cannon Switches)
X1 = 2.4576 MHz quartz crystal
1 pinheader 2x6 pins
5 SIL pinheaders, 3 pins
1 Pactec HPkit enclosure; approx. 92x146x28mm
1 printed circuit board 930134 (see page 70)

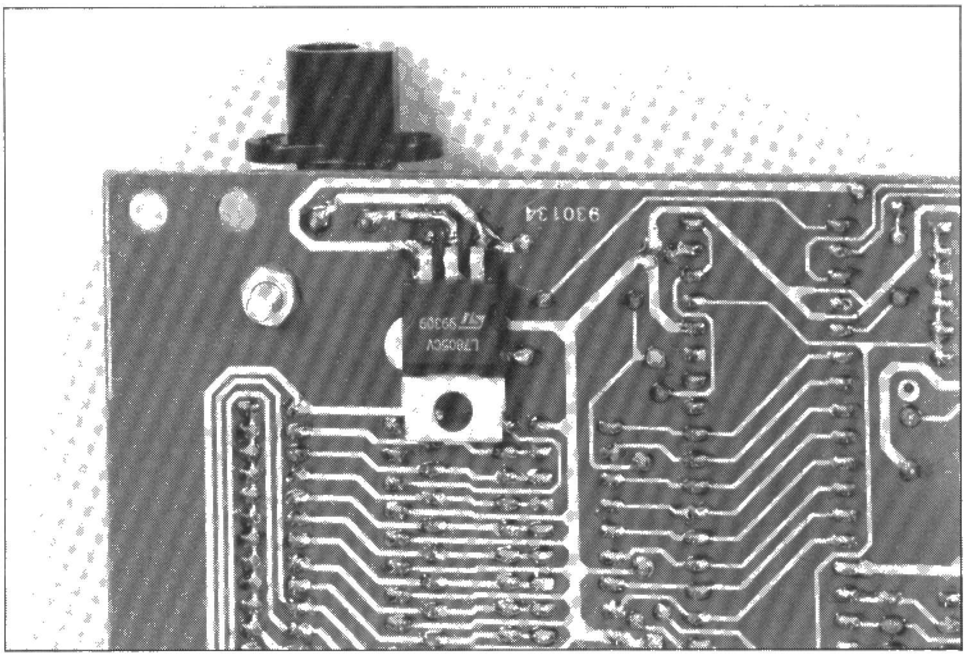
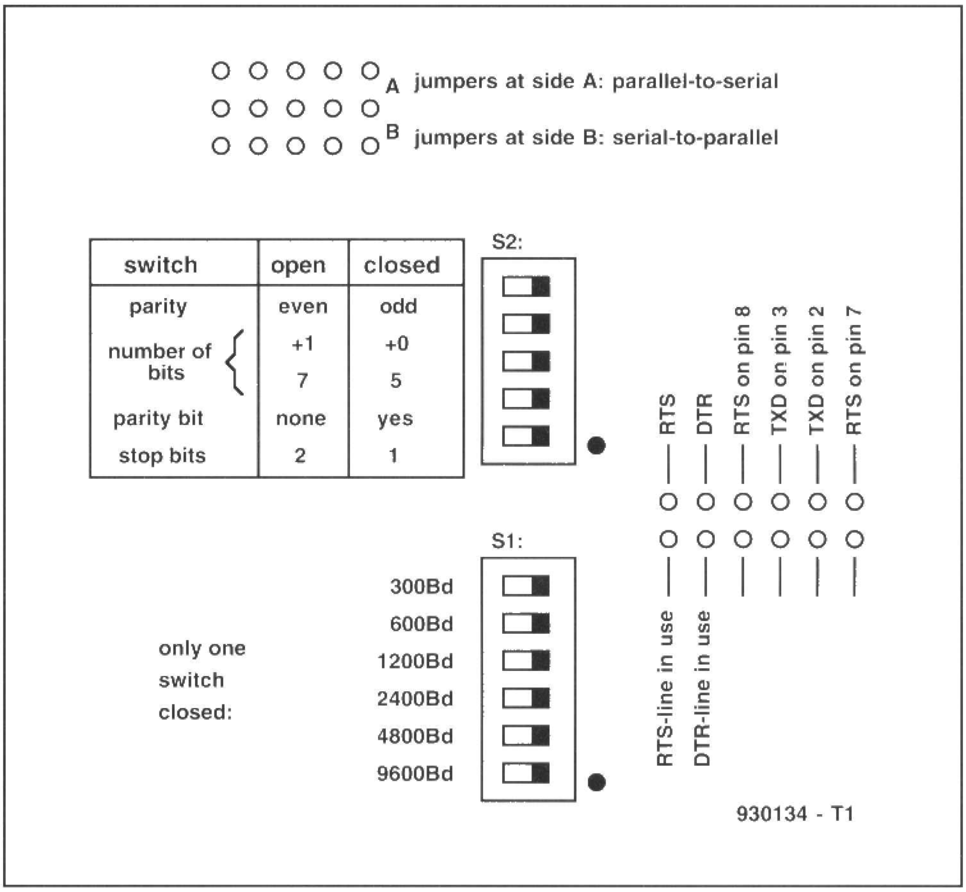


Fig. 5. Unconventionally, voltage regulator IC9 is fitted at the solder side of the board if the plastic enclosure mentioned in the parts list is used.



switch	open	closed
parity	even	odd
number of bits	+1	+0
	7	5
parity bit	none	yes
stop bits	2	1

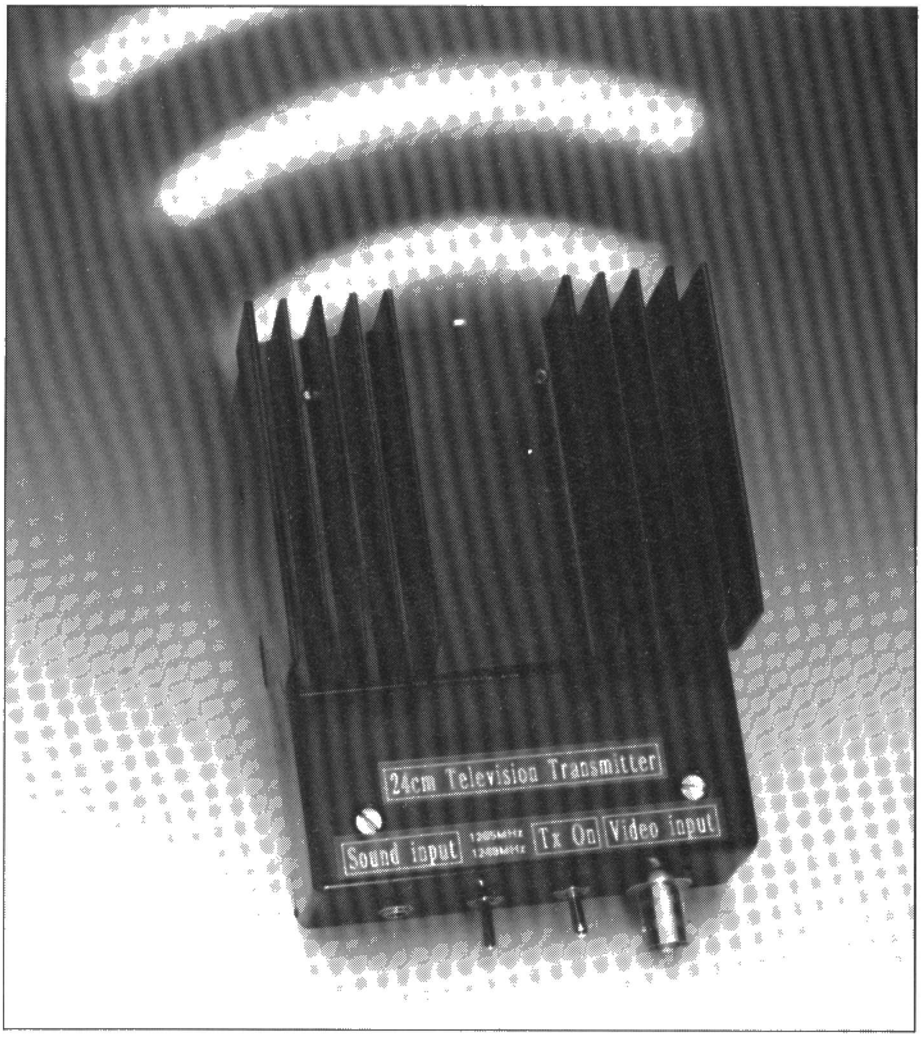
Table 1. Settings of jumpers and DIP switches on the board.

ulator has to be fitted at the solder side of the board — else, it protrudes too far above the board (see **Fig. 5**).

The circuit can not be taken into use before you have fitted the jumpers in the appropriate positions. The five 3-pin PCB headers at the centre of the PCB must all be set to position 'A' or 'B' (A = parallel-to-serial; B = serial-to-parallel). Further, there are six pin combinations next to K_4 that are used to select the lines used for the serial output. Fit two jumpers in the '1' positions if the connection is a 'real' DTE-to-DCE link (i.e., the device connected to the serial output of the converter is a DCE), and a non-crossed connection cable is used. The jumpers are fitted in positions '0' if the connection is of the DTE-to-DTE type with a non-crossed cable, or a DTE-to-DCE type with a crossed cable, or a so-called zero-modem. The enclosure may be closed after fitting the jumpers. The baudrate and the serial data format may be set with the aid of the DIP switches.

Should the serial peripheral equipment have a 25-way D-connector, this may be fitted with a 9-to-25-pin adaptor. ■

24 CM FM AMATEUR TELEVISION TRANSMITTER



This article describes a simple 'sure-fire' FM ATV transmitter which uses surface mount technology throughout. It also outlines how a typical amateur TV station operates, and how to receive either signals direct from an amateur, or via a repeater.

By Tim Forrester G4WIM

FOR some radio amateurs (and most probably the general public at large), the ability to communicate with other people at a distance has lost much of its mystic, possibly due to the sophisticated communications infrastructure most of the modern world now possesses, and the availability of high performance radio equipment for amateur use. However, for most people, these communications are usually limited to speech or fax, with possible use of slow scan TV still images by licensed radio amateurs.

One field where it is still possible for amateurs to experiment and build their own equipment is that of fast scan television. Few visitors (licensed or not) to a ham radio shack equipped with television equipment fail to be enthralled by the ability to talk and see the person 'at the other end', even if the other station is only a couple of miles away.

Building up an ATV station does not have to be time consuming or expensive, especially as many households already have a camcorder and a satellite TV receiver. They only require a suitable transmitter and aerial to transmit pictures (an amateur radio licence is also obviously necessary!).

A brief background to amateur TV

Radio amateurs have been experimenting with fast scan TV (normal broadcast field and line rates) for many years, but due to licence and other technical restrictions experiments were usually conducted on the 435 MHz (70 cm) band. The bandwidth available to amateurs on 70 cm is restricted, which means it is only possible to use amplitude modulation (AM) with colour transmissions just being possible with careful filtering of the transmitter output. The use of ATV repeaters in this band is certainly not possible!

However, many radio amateurs use 435 MHz AM vestigial sideband TV successfully for long distance one-to-one contacts, often over hundreds of miles when propagation conditions are favourable.

Recently, with the advent of cheap satellite TV receivers which cover the 1.3-GHz amateur band, the possibility of high quality FM TV (colour and sound) has been made possible for many amateurs who previously would have thought that operation at such a high frequency would present too many problems. But perhaps more importantly, the 1.3-GHz band with its greater bandwidth has meant that ATV repeaters are able to be licensed.

For those of you who would like more information about amateur TV generally, I suggest joining the British Amateur Television Club (BATC), they can be contacted at 5 Ware Orchard, Barby, Near Rugby, Warwickshire CV23 8UF. *VHF Communications* at the same address as the BATC also frequently publishes ATV related projects.

Choosing a suitable satellite TV tuner

Probably the best way to start discovering what amateur TV (ATV) is all about is to acquire a suitable receiver. The problem is with so many different models and standards, what sort to choose. I would not necessarily recom-

mend dashing off to Dixons and buying the latest hi-tech offering from Japan!

As many satellite viewers regularly upgrade their equipment, it is best to try and search out a second-hand unit which can be modified if necessary. This is the approach most 24-cm ATV beginners tend to take. Often the small ads in the local paper contain suitable tuners which can be modified. At the moment there is a glut of BSB units, some of them brand new, going for under £20. The problem is that they were designed for D2MAC which uses slightly different pre-emphasis and digital sound, so unless you are prepared to spend some time and money modifying them for PAL and building a sound demodulator, I suggest looking for more basic equipment.

The following is a list of tuners which are known to work well with little or no modification. There are many more types which could work equally well, but unfortunately it is beyond the scope of this article to give a complete list. A chat with your local ATV technical expert will probably put you on the right track.

Make	Model
Nokia	SAT1600
Nokia	SAT1700
PACE	PRD800
PACE	PRD900
BUSH	SM1000

Amateur TV repeaters

The main advantage of a repeater is that everyone can see (and hear) everyone else, even if they are using low power from a poor location with nobody else within 'simplex' (one-way) range. Obviously, the better sited (higher) the repeater, the greater the coverage and number of viewers it is likely to have.

The ATV repeater GB3MV, for instance, covers the town of Northampton and surrounding villages. Several stations use powers of less than 50 mW at distances of more than 12 miles away to access the repeater with noise-free pictures. The repeater itself runs 10 watts output into an omni-directional 'Alford' slot aerial which is also used on receive (simultaneously!) by means of careful filtering.

Stations running such low power are able to access the repeater by virtue of its very low-noise (sensitive) receiver and optimized FM demodulator.

There are now a number of active repeaters throughout the country, with more becoming operative every year. Typically, they are left on air 24 hours a day transmitting test cards

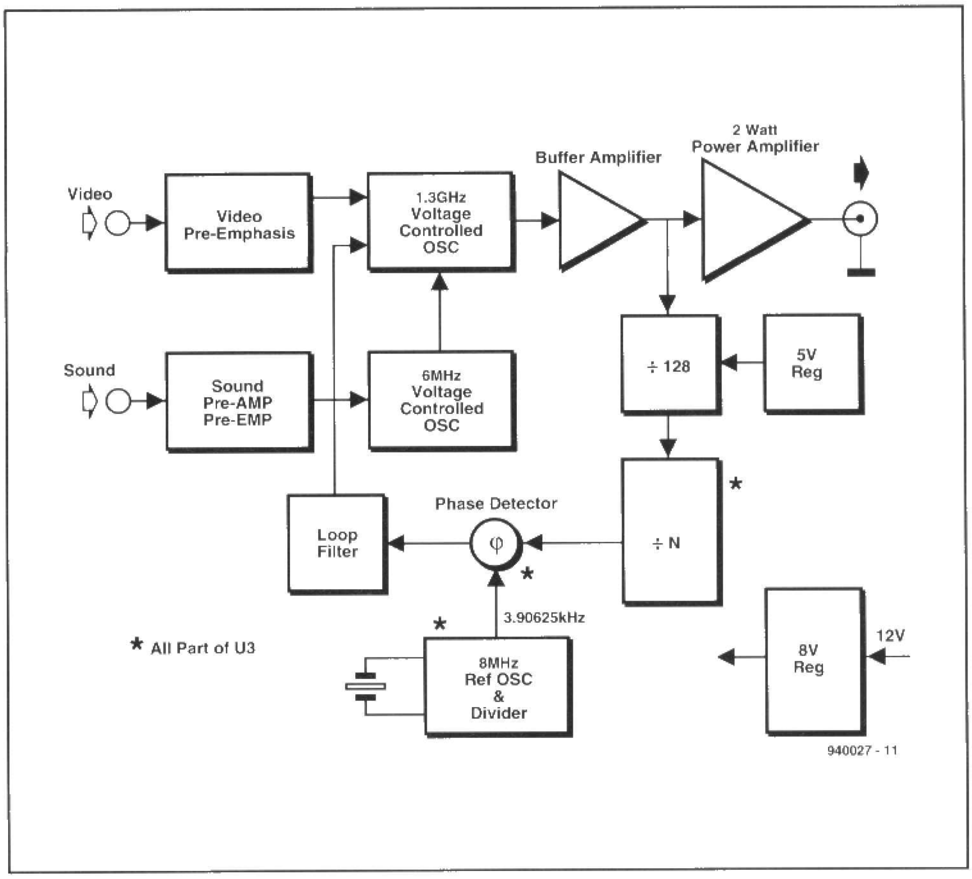


Fig. 1. Block schematic of the ATV transmitter.

Callsign	Channel	Location	Notes
GB3CT	RT2	Crawley	
GB3ET	RTS	Emley Moor	
GB3GT	RT2	Glasgow	
GB3GV	RT2	Leicester	
GB3HV	RT3	High Wycombe	
GB3LO	RT2R	Lowestoft	
GB3MV	RT2R	Northampton	
GB3NV	RT2	Nottingham	
GB3PV	RT2	Cambridge	
GB3RT	RT2	Coventry	
GB3TG	RT103	Milton Keynes	
GB3TN	RT2R	Fakenham	
GB3TT	RT2R	Chesterfield	
GB3TV	RT2	Dunstable	
GB3UD	RT2	Stoke on Trent	
GB3UT	RT1	Bath	Non-operational
GB3VI	RT?	Hastings	Non-operational pending change to FM
GB3VR	RT2	Worthing	
GB3XT	RT103	Burton on Trent	
GB3ZZ	RT2	Bristol	

ATV repeater channel frequencies

Channel	Input freq.	Output freq.	Mode
RT1	1276 MHz	1311.5 MHz	AM
RT2	1249 MHz	1318.5 MHz	FM
RT2R	1249 MHz	1316 MHz	FM
RT3	1248 MHz	1308 MHz	FM
RT101	10200 MHz	10040 MHz	FM
RT102	10255 MHz	10150 MHz	FM
RT103	10250 MHz	10150 MHz	FM

Table 1. Main data on ATV repeaters in the UK.

when not actually being used as a repeater. The test card in beacon mode serves as a useful signal for people wishing to aim their antennas and align receivers. The test card 'pages' contain the usual colour bars and often text carrying local amateur radio news and technical details about the repeater. Every few minutes the repeaters also identify themselves in CW (morse code) on the audio channel.

The presence of a video signal on the repeaters input will result in the repeater becoming active and relaying the signal being received. In most cases, there is no need for tone access as with voice repeaters.

Table 1 gives a list of 1.3 GHz (24 cm) repeaters in the UK along with their channel numbers (apologies if any of the data below is out of date by the time this article is published).

Recently, to increase the coverage area of ATV repeaters, plans are being formulated to link one repeater to another using point-to-point microwave links. Indeed, GB3TG is already linked to GB3TV via 10 GHz (3 cm), and there are plans to link GB3MV to GB3TV via GB3TG on possibly 2.3 GHz (13 cm).

Design of a 24-cm ATV transmitter

Due to the availability of satellite receivers, getting going on receive is usually the first step towards operating on TV and normally presents few problems. Having successfully received some amateur signals, viewers more often than not want to start transmitting as well! The problem is how to construct an effective transmitter, given the inherent problems of 1.3GHz construction.

One of the major hurdles with any

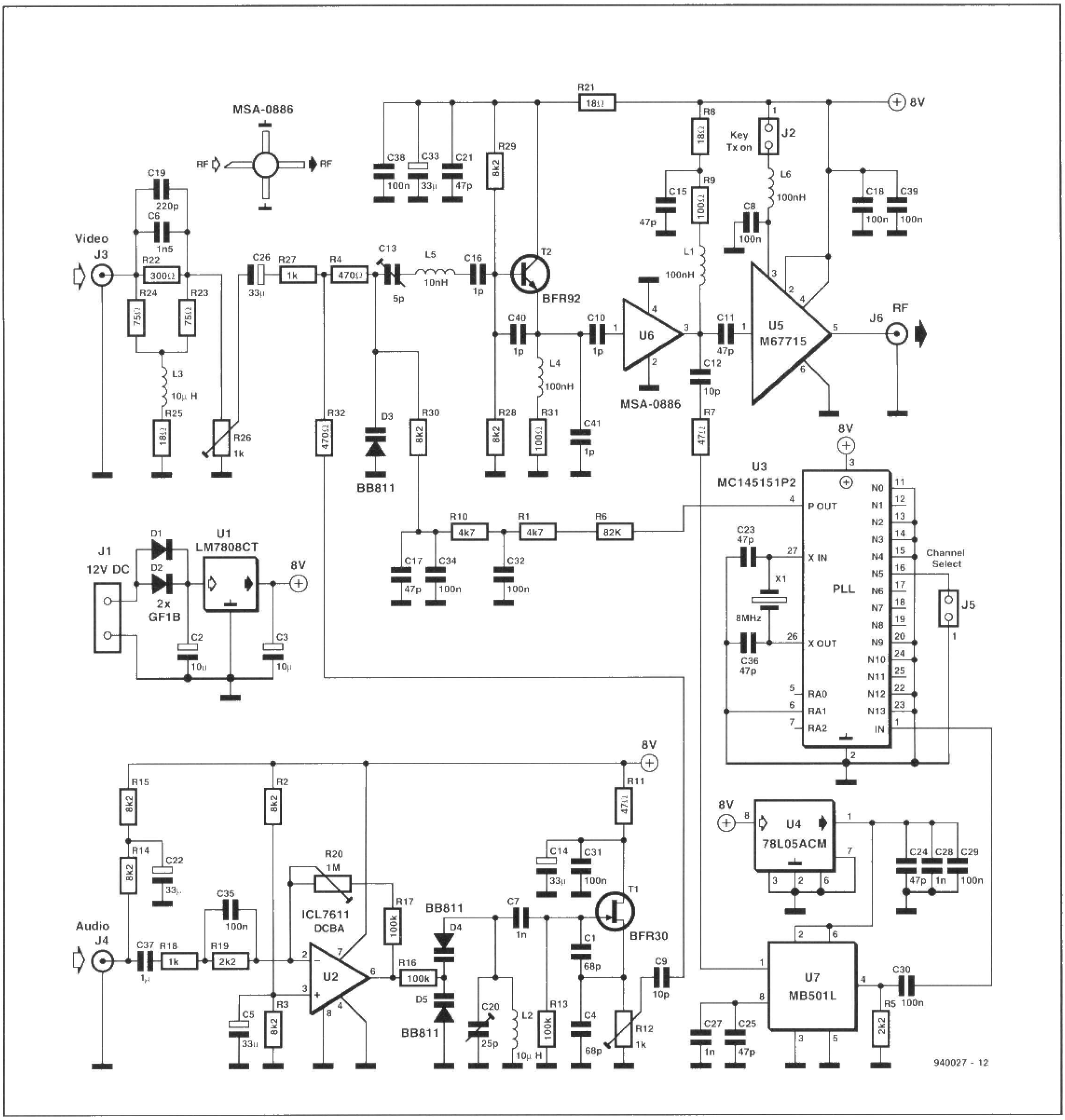


Fig. 2. Circuit diagram of the 24-cm ATV FM amateur television (ATV) transmitter.

1.3-GHz design is consistency, i.e., ensuring that any copy of the design is built exactly the same, even down to component lead lengths, height above the PCB, etc. Other problems are the frequency stability and power output — both must be adequate to ensure a noise free picture into the repeater.

Dealing with the problem of components first, this design is totally surface mount. That means all the components are soldered directly to the board with pre-set lead lengths and at a pre-determined height above the PCB.

This technique ensures a high degree of repeatability, and, as a bonus, a compact, easily portable unit for 'outside broadcast' use!

Obviously, a free-running oscillator at 1.3 GHz is going to drift, but as the receiver bandwidth is typically 15 MHz, that is not too much of a problem. This transmitter, though, is a fairly powerful compact design, and the heat dissipated by other parts of the circuit could lead to unacceptable amounts of frequency drift. Therefore, a simple phase locked loop (PLL) is included to maintain frequency stability — more on the design of the loop later. If operators do not mind the occasional re-tune of the transmitter frequency, it is possible to leave out the PLL circuits and install a potentiometer to set the operating frequency. This approach makes for a unit costing approximately £30 less than for the complete device. Of course, the PLL circuit could always be added at a later date.

RF power gain at 1.3 GHz can be difficult to achieve (and expensive) using individual components. Fortunately these days it is possible to buy RF power amplifiers which come in the form of modules offering guaranteed performance. Their cost is considerably less than buying the individual parts, and there are no alignment problems.

The inclusion of the sound circuitry is very simple, based upon well proven techniques, and does not merit much description. It, too, uses surface mount parts for the sake of consistency and ease of mounting the PCB. Other designs have been published which use more complex audio circuits and sub-carrier oscillators, but it has been found that this simple circuit is perfectly adequate for working simplex and into the repeater. GB3MV actually uses a more complex arrangement to peak-limit the deviation and maintain the sub-carrier frequency to tighter limits.

As mentioned above, 70-cm ATV has traditionally used amplitude modulation (AM) which means that all the modulation stages and subsequent amplifiers had to be linear if picture distortion was to be avoided.

On 24 cm, frequency modulation (FM) is almost universally used. FM offers several advantages over AM for TV work, and few disadvantages. Perhaps the major advantage is that RF amplifiers can operate in class C, i.e., a non-linear, but high efficiency mode. Also, a properly designed FM TV receiver can exhibit a much better picture quality for a lower RF signal to noise ratio at the receiver input. These two reasons alone explain why FM is used for satellite TV broadcasting, and why amateurs have adopted similar techniques and standards.

Broadly speaking, any FM TV transmitter comprises the same basic stages, as follows:

(1) RF oscillator, either on frequency or multiplied to final frequency;
(2) Pre-emphasized FM modulator, usually associated with (1) above;
(3) Frequency maintaining phase locked loop;
(4) Sound amplifier and sub-carrier oscillator;
(5) RF power amplifiers.

As can be seen from the block diagram in **Fig. 1**, the present design follows the basic principles outlined above.

The circuit is given in detail in Fig. 2. The RF oscillator is formed by T_2 running directly at 1.3 GHz. Varicap diode D_3 is used to modulate the oscillator's frequency with both baseband video and the 6-MHz sound sub-carrier. In conjunction with the PLL circuits it also maintains the desired mean frequency.

As FM noise rises with frequency, a better overall system signal to noise ratio can be achieved by boosting (pre-emphasising) the high frequency video signal, and then using de-emphasis at the receiver to restore the desired flat frequency response — the same principle as used on terrestrial FM radio.

In this design, the components between J_3 and R_{26} perform pre-emphasis to CCIR 405, a widely used broadcast standard. Preset R_{26} sets the total video deviation.

Integrated circuits U_6 and U_5 amplify the low-level signal from T_2 up to about 2 watts output.

The transmitter RF output is turned on by applying bias to U_5 via a switch on J_2. The PLL is left running all the time power is applied to the unit.

Circuit U_2 is a the sound pre-amplifier and pre-emphasis circuit, with T_1 being a frequency-modulated 6-MHz oscillator. The exact frequency and level of the sound sub-carrier is set by C_{20} and R_{12} respectively.

The PLL used in this design is very basic and uses only two ICs, U_3 and U_7. There is no loop filter opamp. Instead, the output of U_3 is used directly to drive the loop filter whose output (via R_{30}) controls the mean voltage on D_3, and thus the oscillator frequency. R_1 and R_6 are in series purely to make the PCB layout easier!

U_7 is used as a fixed divide-by-128 prescaler to bring the output of T_2 down to within range of U_3. The reference frequency of U_3 for use with its internal phase detector is 8 MHz divided by 2048, giving a reference of 3.90625 kHz. This results in a channel step of 500 kHz at 1.3 GHz when it is effectively multiplied by 128 with U_7.

For good quality pictures, the overall frequency response of a TV transmitter ideally would be from DC to approximately 5.5 MHz. Usually, the high frequencies are not too much of a problem, provided care is taken with the design. However, when using a PLL which tries to maintain the nominal carrier frequency, if the PLL bandwidth is too great, it can effectively strip off any low frequency components. Therefore, to ensure the PLL cannot attenuate or distort the low frequency frame sync pulses, it must have a loop bandwidth of less than 50 Hz. The design presented here has a loop bandwidth of about 30 Hz, easily low enough to ensure adequate low frequency response.

A side effect of using a low loop bandwidth with a basic design like this is the PLL lock time. Typically, the PLL could take several hundreds of milliseconds to acquire lock from switch on. That is why in this design the PLL is kept 'alive' all the time, and the transmitter turned on by applying bias to the PA. This technique offers the benefit of having a low-level signal present for picture alignment purposes before actually going 'on-air'.

The low loop band bandwidth of 30 Hz also makes it very easy to attenuate any traces of the 3.90625 kHz reference frequency, which may otherwise leak through into the signal path, and modulate the transmission.

By varying the divide ratio in U_3, it is possible to program any other frequency in the band to a resolution of 500 kHz. With a jumper (or switch) across J_5, the transmitter will operate on 1249 MHz, the most popular repeater input frequency. Due to spreads in X_1, C_{23} and C_{36}, the reference oscillator may not be exactly on 8 MHz, and may result in a slight frequency offset of up to 100 kHz — not a problem with a 15-MHz receiver bandwidth! If desired, C_{23} could be trimmed to ensure operation on exactly 1249MHz.

Leaving J_5 open-circuit results in the transmitter operating on 1265 MHz for simplex operation. All the 'N' programming inputs to U_3 have internal pull up resistors, so its quite

COMPONENTS LIST

Resistors:
All resistors and presets SMT 0.25W.
Resistors size 1206.
R1;R10 = 4kΩ7
R2;R3;R14;R15;R28;R29;R30 = 8kΩ2
R4;R32 = 470Ω
R5;R19 = 2kΩ2
R6 = 82kΩ
R7;R11 = 47Ω
R8;R21;R25 = 18Ω
R9;R31 = 100Ω
R12;R26 = 1kΩ preset (Bourns 3304W)
R13;R16;R17 = 100kΩ
R18;R27 = 1kΩ
R20 = 1MΩ preset (Bourns 3304W)
R22 = 300Ω
R23;R24 = 75Ω

Capacitors:
All capacitors SMT series ATC100A, size 0805 unless otherwise noted
C1;C4 = 68pF
C2;C3 = 10µF electrolytic
C5;C14;C22;C26;C33; = 33µF tantalum
C6 = 1nF5
C7;C27;C28 = 1nF
C8;C18;C29-C32;C34;C35;C38;C39 = 100nF ceramic, size 1206
C9;C12 = 10pF
C10;C16;C40;C41 = 1pF
C11;C15;C17;C21;C23;C24;C25;C36 = 47pF
C13 = 5pF trimmer (Stettner)
C19 = 220pF
C20 = 25pF trimmer (Stettner)
C37 = 1µF ceramic, size 1206

Semiconductors:
D1;D2 = GF1B
D3;D4;D5 = BB811
T1 = BFR30
T2 = BFR92
U1 = LM7808CT
U2 = ICL7611DCBA
U3 = MC145151P2 (Motorola)
U4 = 78L05ACM
U5 = M67715 (Mitsubishi)
U6 = MSA-0886 (Avantek)
U7 = MB501L flatpack (Fujitsu)

Inductors:
All inductors SMT, Siemens SMD02
L1;L4;L6 = 0µH1
L2;L3 = 10µH
L5 =10nH

Miscellaneous:
J1-J6 = 2-pin header
X1 = 8MHz crystal
Printed circuit board (see p.22).
Diecast case, Hammond 1590BB.
Heatsink 7.5x9.7x2.5cm. (SK04 75mm)
BNC socket.
2 miniature on/off switches.
Jack (3.5mm) and DC supply socket.
SMC RF socket.

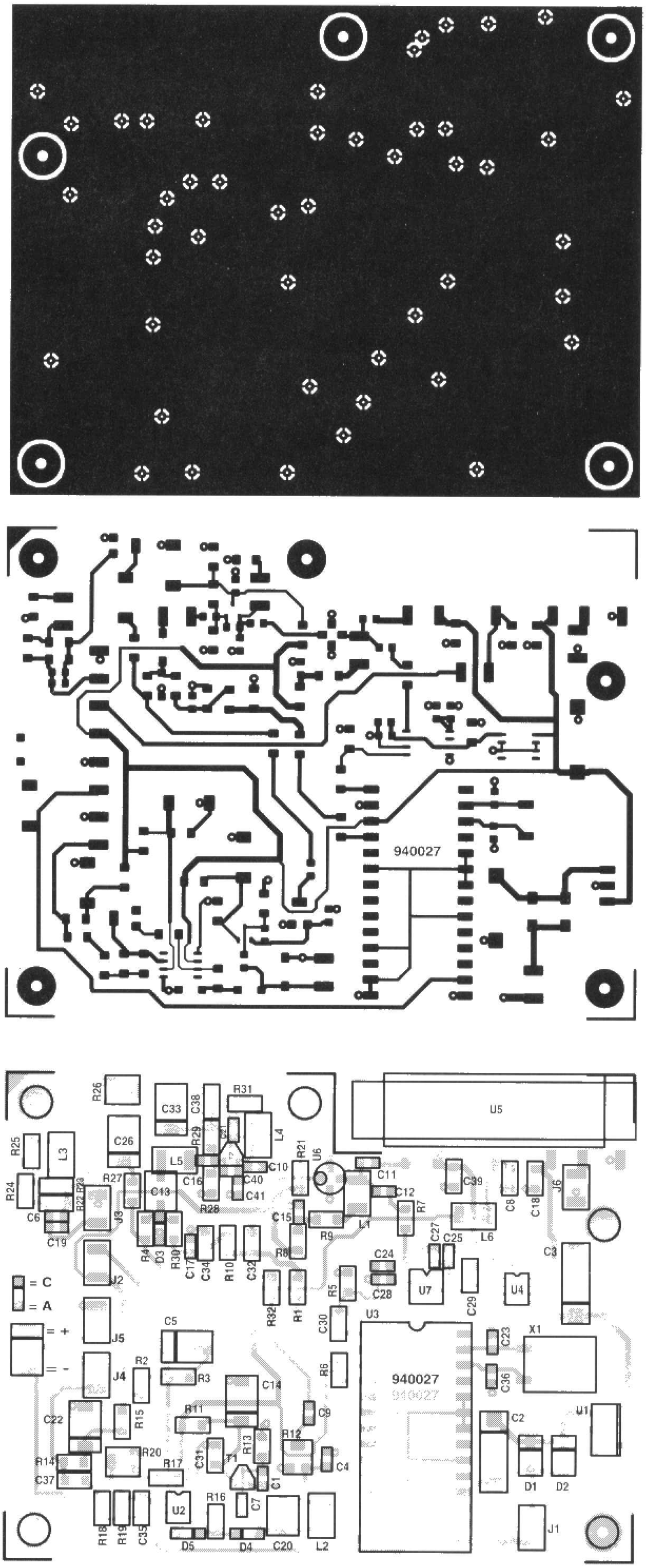


Fig. 3. Artwork for the double-sided fibreglass printed circuit board designed for the transmitter.

in order to leave J_5 open-circuit.

Construction

Virtually all the parts used in this design are readily available surface mount types, however there are a few parts which are normally leaded. X1, U_1 and U_3 require converting to surface mount, easily achieved by forming the leads to fit the pads on the PCB.

Generally, the use of surface mount parts throughout makes installing the PCB into a case very easy with no need for special spacers etc. Additionally, by fastening the PCB directly down to the case, a good earth is ensured between the PCB ground plane, RF power amplifier module and the case. This, in turn, leads to a more reproducible design with less chance of RF instability due to circulating earth currents.

The PCB is designed to fit into a standard diecast box approximately 120 × 95 × 3.5 cm (4.75 × 3.75 × 1.4 inch). If continuous operation is envisaged, an additional heatsink is recommended. **Figure 4** shows how the PCB and controls are arranged.

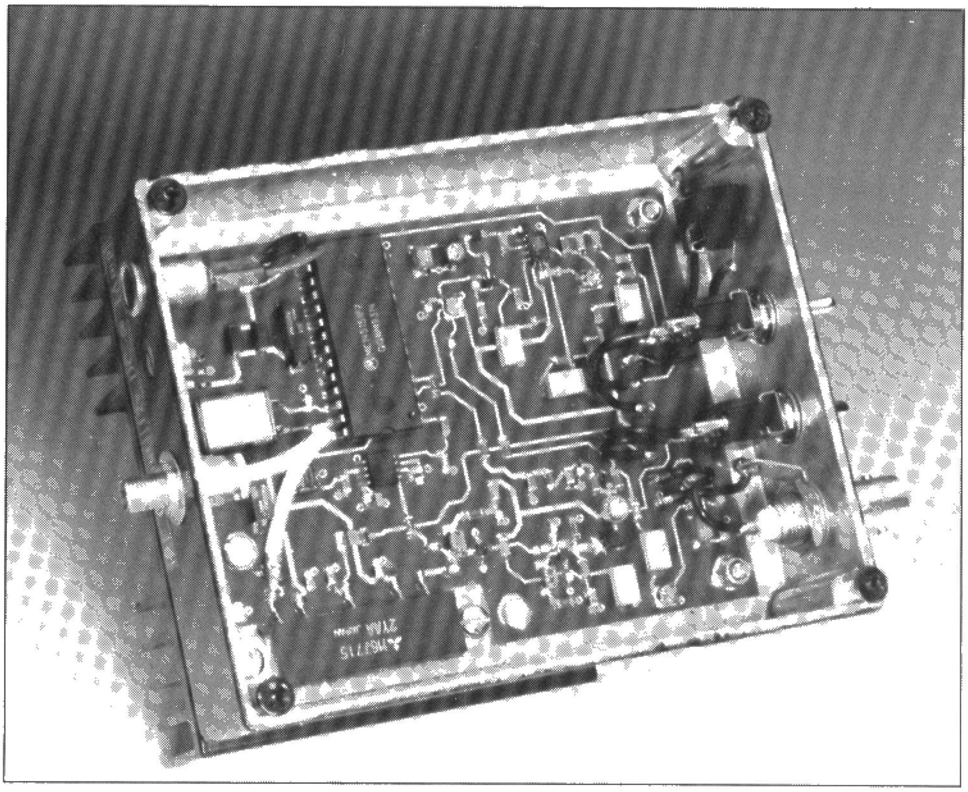


Fig. 4. Internal view of the author's prototype. Note how the PA module is bolted to the bottom of the enclosure and the heatsink on the back.

In certain critical areas operating at 1.3 GHz, ATC capacitors are used. I would not recommend using any other manufacturer, otherwise the circuits may not operate as intended.

Building the unit up is very easy, providing a small-tipped iron, a pair of tweezers and fine gauge (32SWG or similar) solder are used. It is recommended that all passive parts are loaded first, followed by the semiconductors, leave fitting the RF power amplifier till last when the unit has been tested and is ready to be finally installed in its case.

Ensure that when loading polarized components (especially diodes and capacitors) they are fitted the correct way around. An obvious statement, but when using surface mount components it is sometimes difficult to identify which end is which. **Figure 3** shows the location of all parts on the PCB, and identifies the polarity of diodes and electrolytic capacitors by means of a bar. So, with reference to the circuit diagram in **Fig. 2** it is possible to determine the correct orientation.

While building the unit, take care to inspect each joint as its made. Then, if possible, before applying power, wash the PCB in a suitable solvent and then check all the joints again. Care in construction will save many hours of faultfinding and possibly damaged components.

Testing

It is assumed that constructors have no suitable 1.3-GHz test equipment, but do have a satellite receiver, a source of composite video and a DVM or high-impedance multimeter.

The first step is to ensure that the PLL is operating and holding the frequency on 1249 MHz. Make sure that J_5 is in place, then apply power. Monitor the voltage at the junction of R_{10} and R_{30}. Next, adjust C_{13} until the voltage reading is approximately 4 V. Remove the trimming tool after each adjustment as stray capacitance from the trimming tool will often affect the oscillator's free-running frequency and hence the required control voltage from the PLL.

Remove the link, so programming the PLL for 1265 MHz, and note that the voltage increases to something less than 7.5 V. If all is well, replace the link and tune the satellite receiver to 1249 MHz. A blank raster or similar should be on the screen.

A small aerial (even a piece of wire would suffice) connected to the solder spot for pin 1 of U_5 may be necessary to ensure an adequate signal for the satellite TV tuner, but take care not to overload the receiver.

Set both R_{12} and R_{26} fully counter-clockwise. Next, apply a video signal to J_3. Gradually turn R_{26} clockwise until a picture is seen with a good balance between contrast and grey scale. Ideally, use a pattern generator as a source of video.

Connect an electret microphone to J_4, and set R_{20} mid-way. Make sure that the satellite tuner sound channel is set for 6 MHz. While watching the picture, turn R_{12} until a slight patterning can be seen, then reduce it until it just becomes invisible. Adjust C_{20} for maximum quieting on the sound channel combined with best audio quality.

Following the above procedure should be sufficient to get the unit operating, but some of the settings may require fine adjustment 'on air' when working a more distant station.

Having completed the preliminary low power alignment, install the PCB into its case and solder the RF power amplifier in place, along with the RF output cable and other connections. With reference to the photograph in **Fig. 4**, note the use of copper tape under the PA module and PCB to aid RF earthing.

If an RF output power meter or dummy load is available, connect it to the RF output, and with an ammeter in series with the main supply, turn the unit on and key the transmitter on by linking J_2. The total current drawn should be just under 1 A, and the RF output power approximately 2 W. Standby current should be about 75 mA.

Connecting the unit to an aerial is all that is required to go 'on air'.

I would recommend the use of a G3JVL quad loop yagi aerial, as this particular design offers excellent gain

and, perhaps more importantly, adequate bandwidth to cover both repeater input and output frequencies. The designer of this antenna, Mike Walters G3JVL, can be contacted at 26 Fernhurst Close, Hayling Island, Hants. PO11 0DT.

Often two aerials are used, one for transmit and one for receive. If they are placed sufficiently far apart it is usually possible to run 'look through' on a repeater without any additional filtering.

ATV operation

Ideally all amateurs aiming to use ATV should try to run 'look through' when operating through a repeater. Running 'look through' offers several advantages, probably the most important being able align and adjust your signal through the repeater for best effect. Secondly, if any one else wishes to use the repeater, he or she can usually be seen to cause patterning. Etiquette normally decrees that the present user drop out and let the other station operate!

One of the unusual aspects of ATV is that when a station is on air, other people (usually unlicensed) often get in on the act and find themselves being televised and sometimes having a conversation with the person on the receiving end! It seems to be an unwritten rule that this is permissible, providing the license holder is present to monitor proceedings. On this basis ATV can get the whole family involved in the hobby!

For those stations watching but not able to transmit, talkback usually takes place on 144.750 MHz or 144.725 MHz, so offering full duplex operation of sound.

NOTE If all of the above has got you fired-up and keen to disconnect the satellite tuner from the LNB and fit a 23cm aerial in its place, a word of caution. The d.c. power for LNB units is sent up the coax. That is OK if you are planning to fit a mast head preamp, and power it in the same manner as the LNB, but if your tuner has sufficient sensitivity or you live close to the repeater and decide you don't need a pre-amp, then be careful to either disconnect the DC feed inside the tuner, or use an aerial which is a DC open circuit.

Otherwise you stand a chance of shorting out the LNB power feed. If it is not current-limited, you could do some damage. Some tuners however have an LNB fuse, in which case it is just a matter of removing the fuse when using an external aerial which is a short to d.c.

Conclusion

In an article such as this it is impossible to cover and explain all the various aspects of ATV operation, but it is hoped that a little light has been shed on the subject for those readers who have never heard of amateur TV.

Television is a very technical field and much more demanding in terms of equipment performance and operation than, say, voice communication. However, because of these problems, the rewards for success are that much greater and well worth the effort.

Well that's about it, hope to SEE you soon! ■

A high-quality printed circuit board for the 24cm ATV transmitter is available from the author. For price and ordering information, write to **T. Forrester, 24 Corran Close, Dallington, Northampton NN5 7AL**. The author also supplies some of special components used in this project. Two suggested sources for the M67715 are Electronic Microwave Components (EMC) Ltd. (0376) 561116, and Misubishi Semiconductor Division (0707) 276100.

MINI PREAMPLIFIER

Design by T. Giesberts

The two major properties of the design described are simplicity and quality. Simplicity is achieved by omitting such superfluous facilities as tone control, mono-stereo selection, rumble filters, noise filters, and so on. Such measures also improve the quality, which may be further enhanced by the use of the best available components

The changes that have taken place in the audio world over the past decade are reflected in design philosophy. In the past there were two clear camps in audio engineering: one that advocated full control of frequency, the use of various filters, and so on, and the other which wanted the minimum of controls. Nowadays, what is the use of a 33/78 input and a rumble filter in the absence of a record player? Why have a noise filter when available signal sources do not produce noise? And what is the use of a mono-stereo selector? Moreover, the quality of current signal sources and the recording quality of compact discs surely make tone control, and equalizers superfluous?

When all these facilities are omitted, what is left? Only the basic functions: input selection, volume control, balance control, and perhaps a separate selector for record out. These functions require relatively few components and that is an aspect that audio purists have always seen as a great plus point. After all, what is not there can not cause noise or distortion.

The design

Figure 1 shows that the omissions discussed earlier result in a fairly simple circuit. The input signals enter via phono sockets K_1–K_{12}. Each of the inputs is individually terminated by R_1–R_{12}. Switch S_1 selects the record out signal, which is applied to output sockets K_{13} and K_{14} via R_{13} and R_{14}. Switch S_2 functions as the standard input selector.

The signals at poles **A** and **B** of S_2 (left-hand and right-hand channels respectively) are applied to a further terminating resistor, R_{15} (R_{16}). The overall terminating impedance of the selected input has the standard value of 47 kΩ. The signals are then applied to a buffer stage, IC_1 and IC_2, which is arranged as a unity gain amplifier. Since the NE5534 is not inherently unity gain stable, a compensation capacitor, C_1 (C_2), is connected between pins 5 and 8.

The output of the buffer is applied to a voltage amplifier, IC_3 (IC_4) via balance control P_1 and volume control P_2. The amplification of IC_3 (IC_4) is set to ×5.5 with the aid of R_{22}–R_{23} (R_{25}–R_{26}). This ensures that in spite of the losses in the balance control a nominal output level of 1 V is obtained with an input of 250 mV.

The outputs of IC_3 and IC_4 are applied to output sockets K_{15} and K_{16} respectively via contacts of relay Re_1. Delay stage T_1 arranges for the relay to be energized a few seconds after the supply has been switched on. This ensures that any switch-

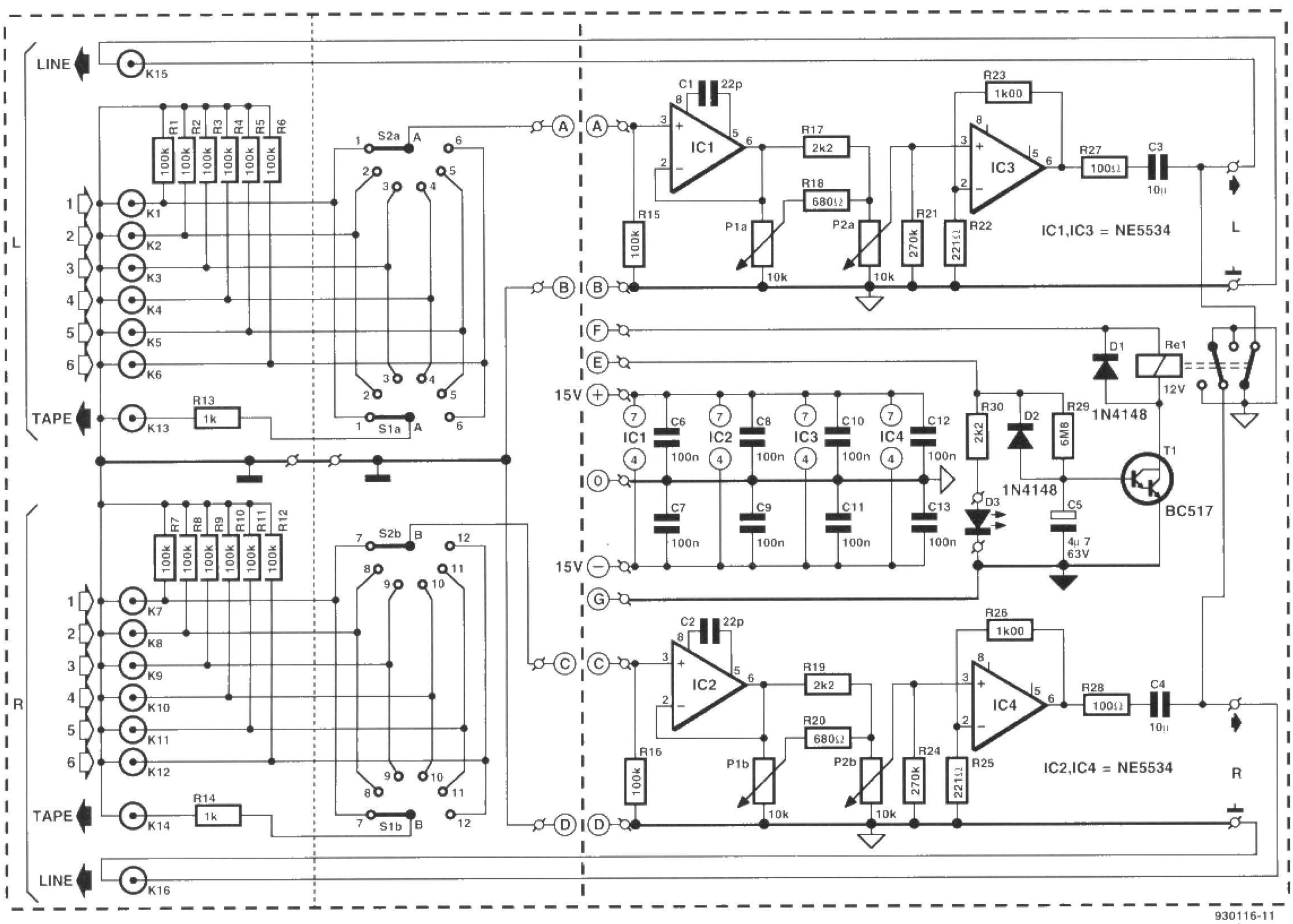


Fig. 1. Circuit diagram of the mini preamplifier.

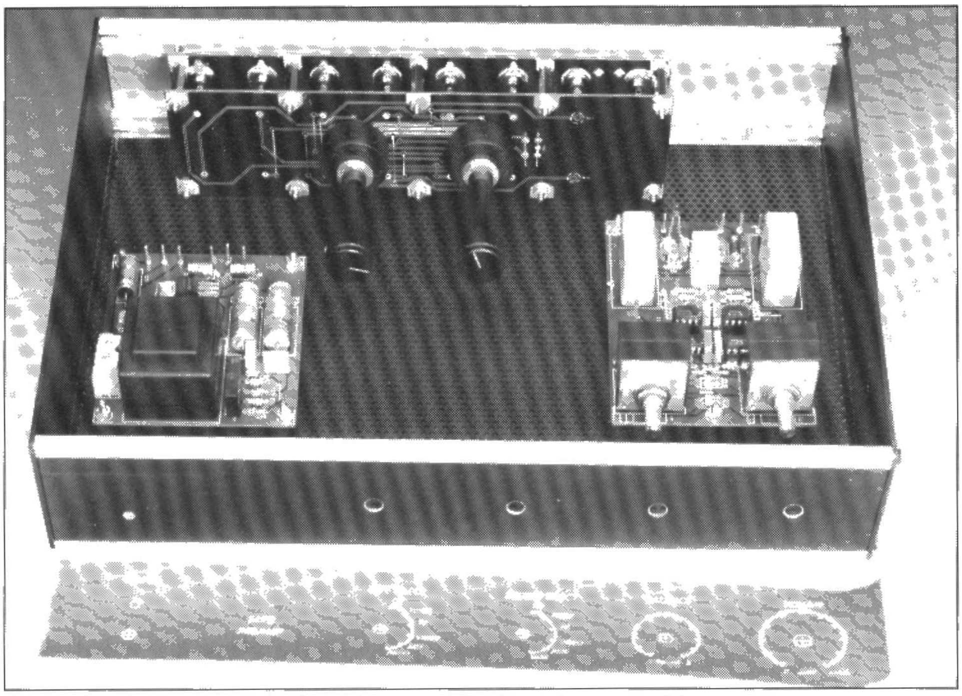


Fig. 2. General view of the (nearly completed) mini preamplifier.

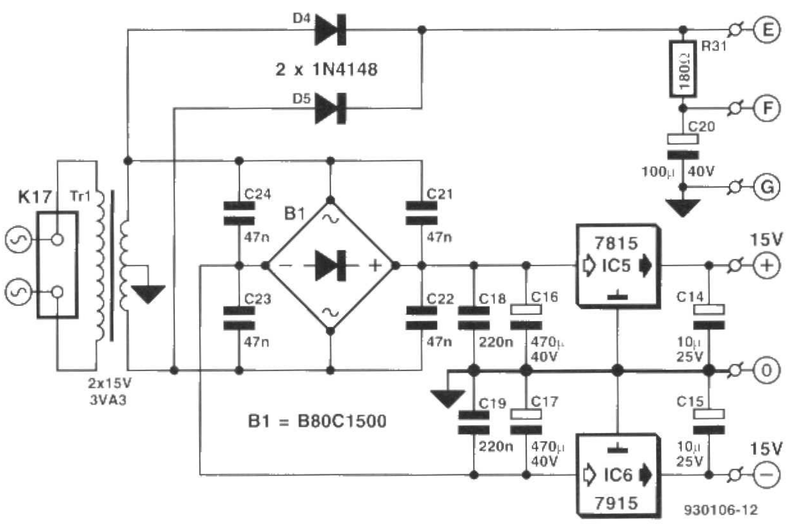


Fig. 3. Circuit diagram of the power supply for the mini preamplifier.

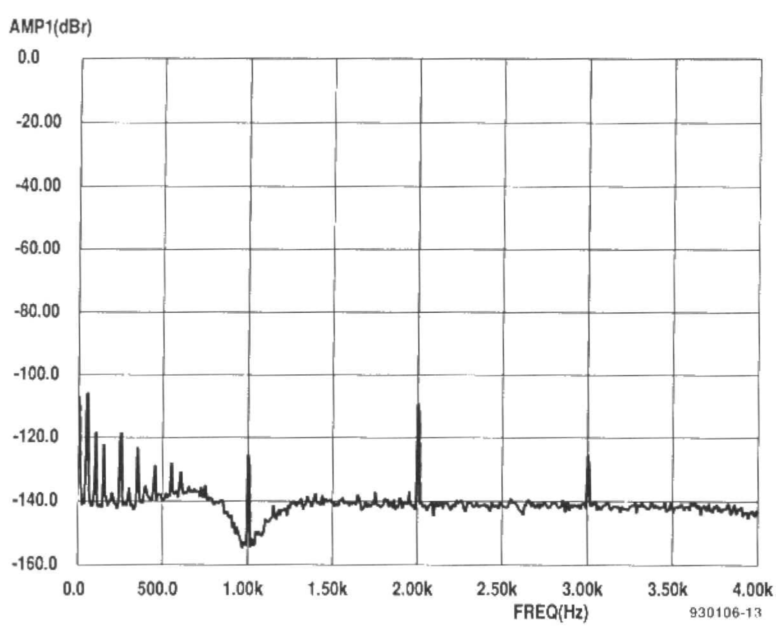


Fig. 4. The THD characteristic leaves little to be desired.

on noise is kept away from the outputs. On-off indication is given by D_3-R_{30}.

The design of the power supply follows the same philosophy as the amplifier: no complicated circuits where simple ones will do. Circuits IC_5 and IC_6 are voltage regulators. The delay stage derives its own supply directly from the secondary of the mains transform er via D_4, D_5, R_{31}, C_{20}.

Enhancement measures

Quality starts with the constituent components. For example, there are many types of phono input socket available, but for best results only gold-plated ones will do. Good-quality rotary switches are also a must, but these can prove difficult to obtain. The type of potentiometer used for the balance and volume controls has a very real influence on the quality of the amplifier. Again, for best results, use a top quality type, such as Alps. Capacitors C_3 and C_4 should preferably be MKT types, but MKP ones will do as well. Note, however, that the printed circuit board (see **Fig. 5**) can cope with less expensive types of passive components as well.

There is a wide choice of integrated circuits as shown in the parts list. This does not mean that the NE5534 used in the prototype is not a satisfactory choice, but there are other, more expensive, types that may meet an individual need better. It should, however, be borne in mind that a more expensive device does not always provide better aural quality.

Of course, there are different yardsticks for the buffer and the amplifier. For the buffer, low noise and a high input impedance are prime requirements, whereas for the amplifier a good gain-bandwidth product and a low output impedance are important. The slew rate reflects much about the quality of an opamp, but its importance in top-quality audio equipment must not be exaggerated: other parameters may be just as important.

Since few people will be able to try out all the operational amplifiers in the parts list, the author's recommendations are the SSM2131 for IC_1 and IC_2 (the OPA627 is also excellent, but perhaps rather expensive for this application) and the OPA637 for IC_3 and IC_4. In the latter case, the LT1028 and OP37 are good second choices. Bear in mind that all types which are not unity gain stable require special compensation when they are used as buffers. This compensation varies from one type to another and is not always wholly satisfactory. It is, therefore, best if the recommended type is not used to choose another that is unity gain stable. Compensating capacitors C_1 and C_2 should be omitted when unity gain stable types are used.

Construction

Before construction is started, cut or saw the printed circuit board in **Fig. 5** into four along the lines indicated. Populating

the four constituent boards should prove straightforward.

Interconnect E, F, G '–', 0 and '+' on the supply board and the amplifier board with appropriate lengths of flexible circuit wire.

Sandwich the other two boards together with the aid of spacers as shown in **Fig. 7** and interconnect them with short lengths of bare wire. The interconnections between the boards near K_{13} and K_{14} is via R_{13} and R_{14}. Note that resistors R_1–R_{12} are soldered directly to the terminals of the phono sockets. When the sandwich has been completed, connect A, B, and C, D to the amplifier board via two short lengths of screened cable.

Connect the outputs of the amplifier board to output sockets K_{15} and K_{16} via two lengths of screened cable.

The boards can then be built into a suitable enclosure. It is the intention that the sandwiched boards are mounted on the inside rear panel and that the spindles of the rotary switches are extended to the front panel—see **Fig. 8**. A suggested front panel suitable for a number of enclosures is shown in **Fig. 6**. It should not prove difficult to adapt this to a particular enclosure.

Some parameters

- The input sensitivity is 250 mV into 47 kΩ for an output of 1 V into 100 Ω.
- Channel separation is 82 dB at 1 kHz.
- Noise suppression and total harmonic distortion (THD) are shown in **Fig. 4**.

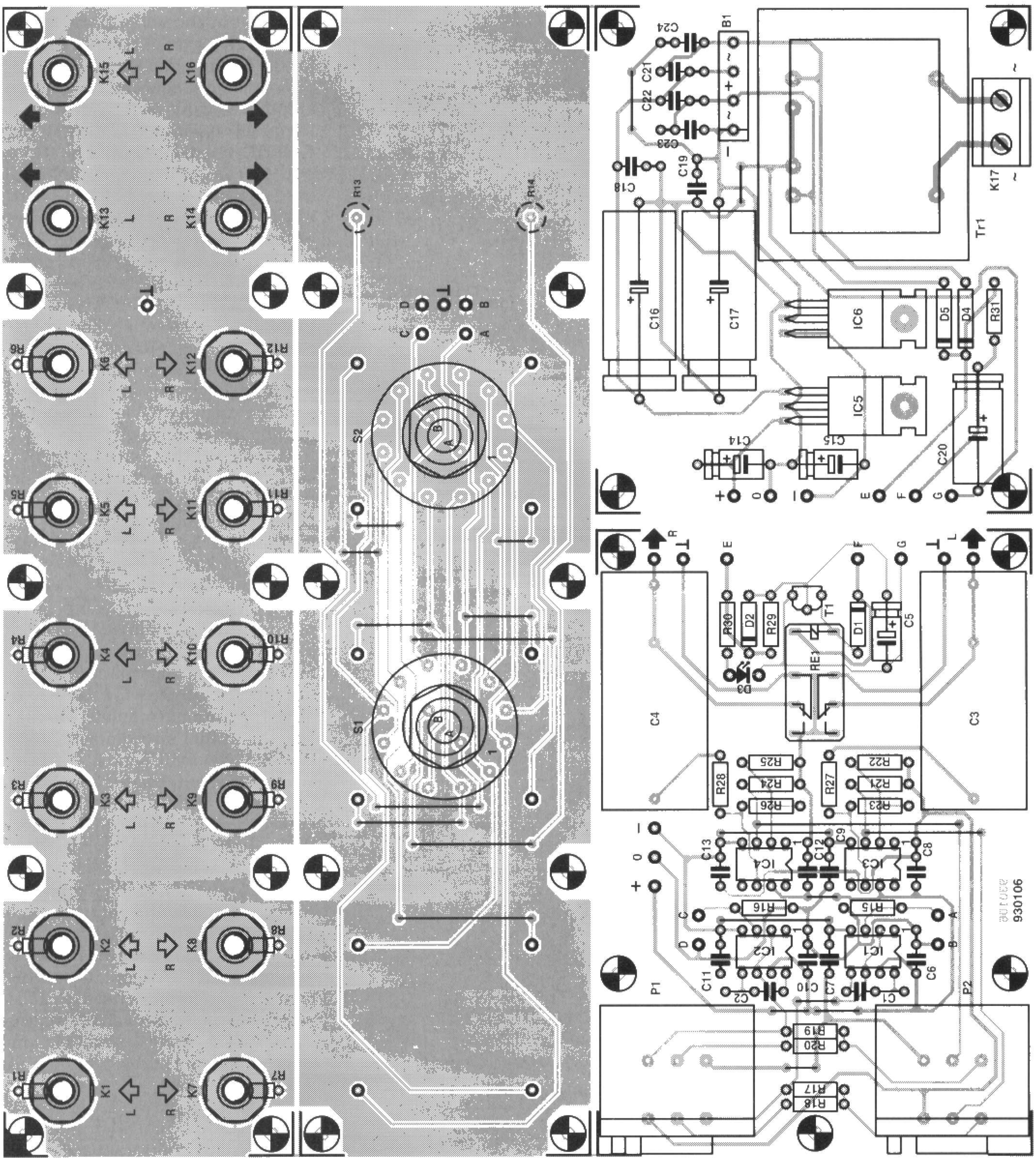


Fig. 5 (a). Printed circuit board (component layout) for the mini preamplifier.

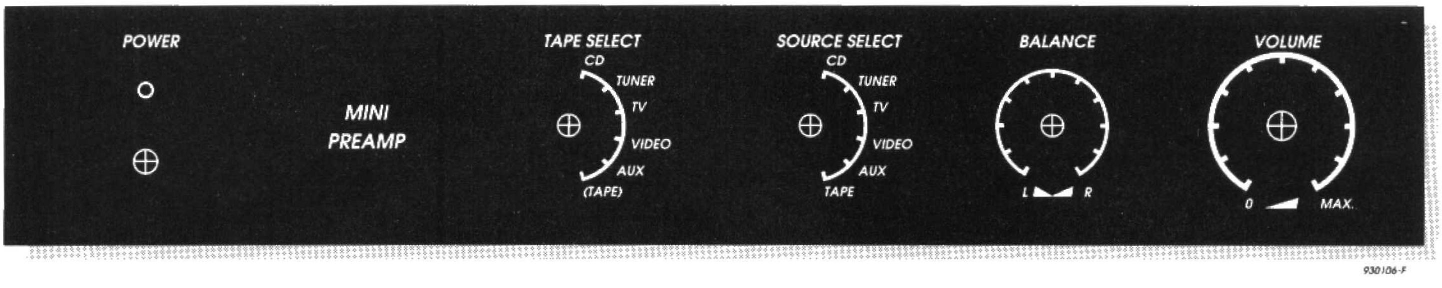


Fig. 6. Suggested front panel layout (not to scale). There is no ready-made foil available.

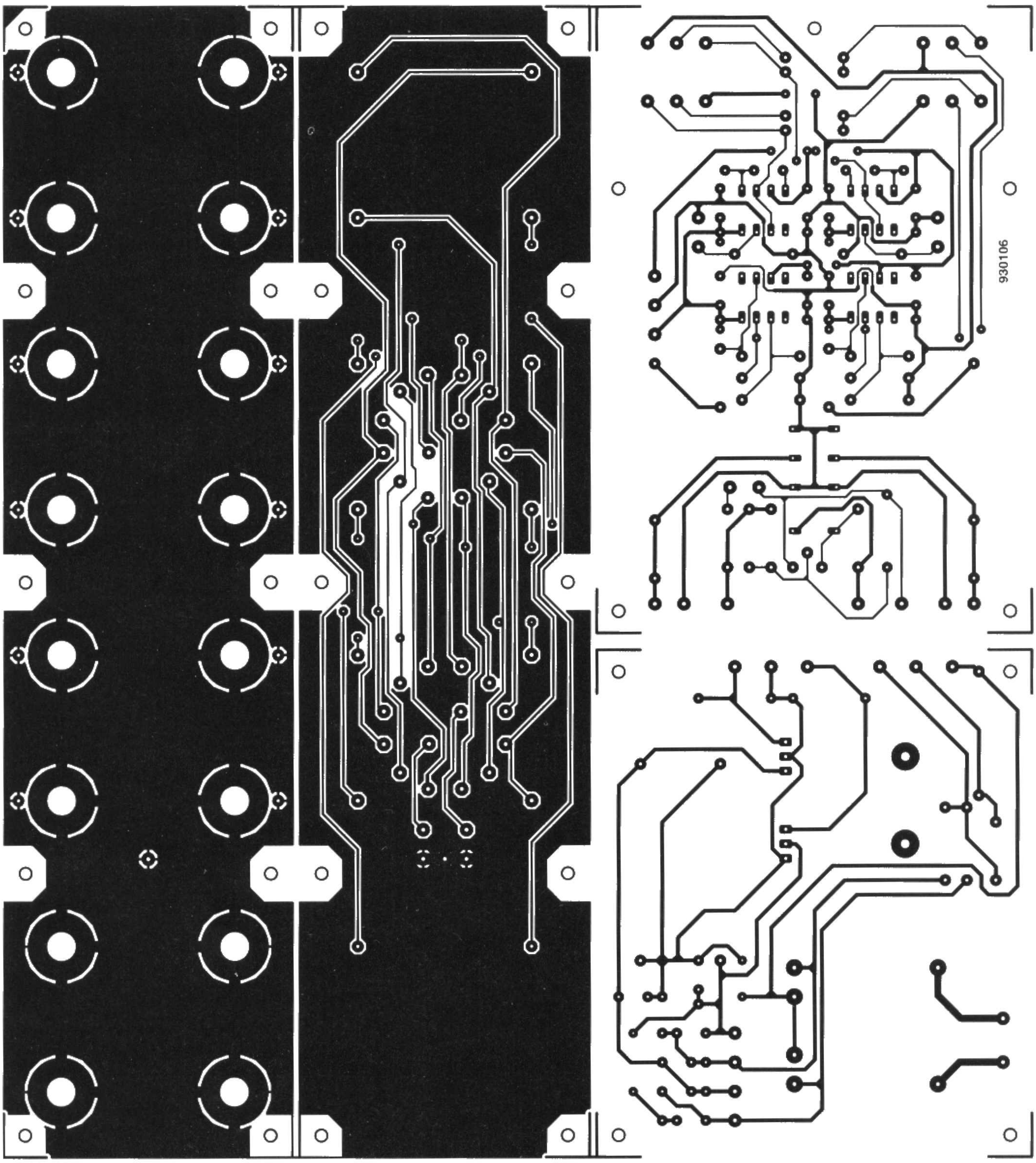


Fig. 5 (b). Printed circuit board (track layout) for the mini preamplifier.

Parts list

Resistors:
R_1–R_{12}, R_{15}, R_{16} = 100 kΩ
R_{13}, R_{14} = 1 kΩ
R_{17}, R_{19}, R_{30} = 2.2 kΩ
R_{18}, R_{20} = 680 Ω
R_{21}, R_{24} = 270 kΩ
R_{22}, R_{25} = 221 Ω, 1%
R_{23}, R_{26} = 1 kΩ, 1%
R_{27}, R_{28} = 100 Ω
R_{29} = 6.8 MΩ
R_{31} = 180 Ω

Potentiometers:
P_1 = 10 kΩ, linear, stereo
P_2 = 10 kΩ, logarithmic, stereo

Capacitors:
C_1, C_2 =22 pF
C_3, C_4 = 10 μF, MKT (polytherephtalate)
C_5 = 4.7 μF, 63 V
C_6–C_{13} = 100 nF
C_{14}, C_{15} = 10 μF, 25 V
C_{16}, C_{17} = 470 μF, 40 V
C_{18}, C_{19} = 220 nF
C_{20} = 100 μF, 40 V
C_{21}–C_{24} = 47 nF, ceramic

Semiconductors:
D_1, D_2 = 1N4148
D_3 = LED, 3 mm
D_4, D_5 = 1N4003
B_1 = B80C1500
T_1 = BC517

Integrated circuits:
IC_1–IC_4 = See text:
NE5534 (bipolar)
SSM2131 (FET)
SSM2134 (bipolar)
OP27 (bipolar);
OP37 (bipolar
OPA627 (FET)
OPA637 (FET)
LT1028 (bipolar)
LT1115 (bipolar)
TLE2027 (bipolar)
TLE2037 (bipolar)
AD743 (FET)
AD745 (FET)
LT1007 (bipolar)
LT1037 (bipolar)
LM627 (bipolar)
LM637 (bipolar)
IC_5 = 7815
IC_6 = 7915

Miscellaneous:
K_1–K_{16} = phono socket for board mounting
K_{17} = 2-way terminal block, pitch 7.5 mm
S_1, S_2 = 2-pole, 6-position rotary switch for board mounting
Re_1 = 12 V miniature relay with 2 change-over contacts for board mounting
Tr_1 = mains transformer, secondary 2×15 V, 3.3 VA
Enclosure as appropriate
Mains socket for panel mounting
Mains on/off siwtch
PCB Ref. 930106 (see p. 70)
Front panel foil (Not available ready made)

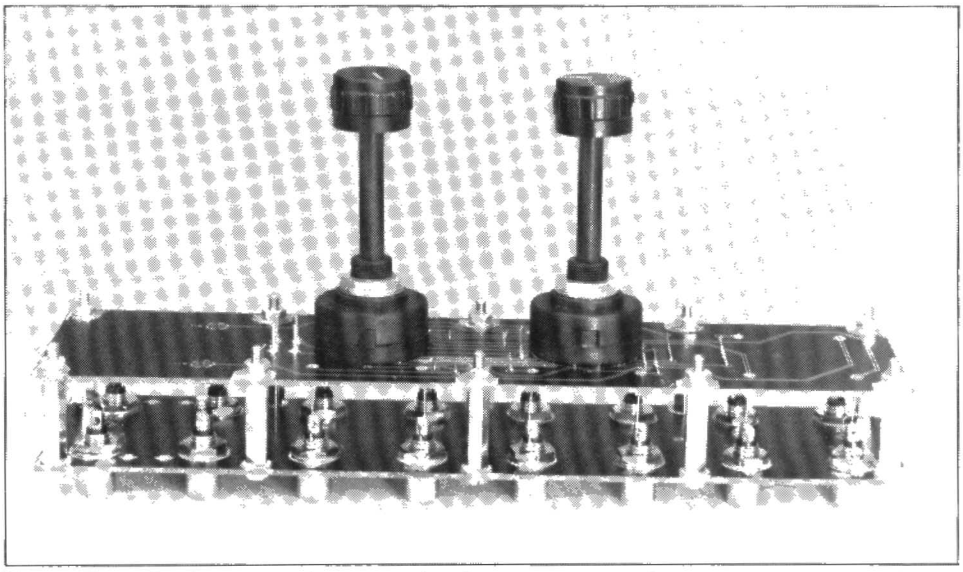


Fig. 7. The print for the sockets and that for the rotary switches are assembled into a 'sandwich' with the aid of suitable spacers.

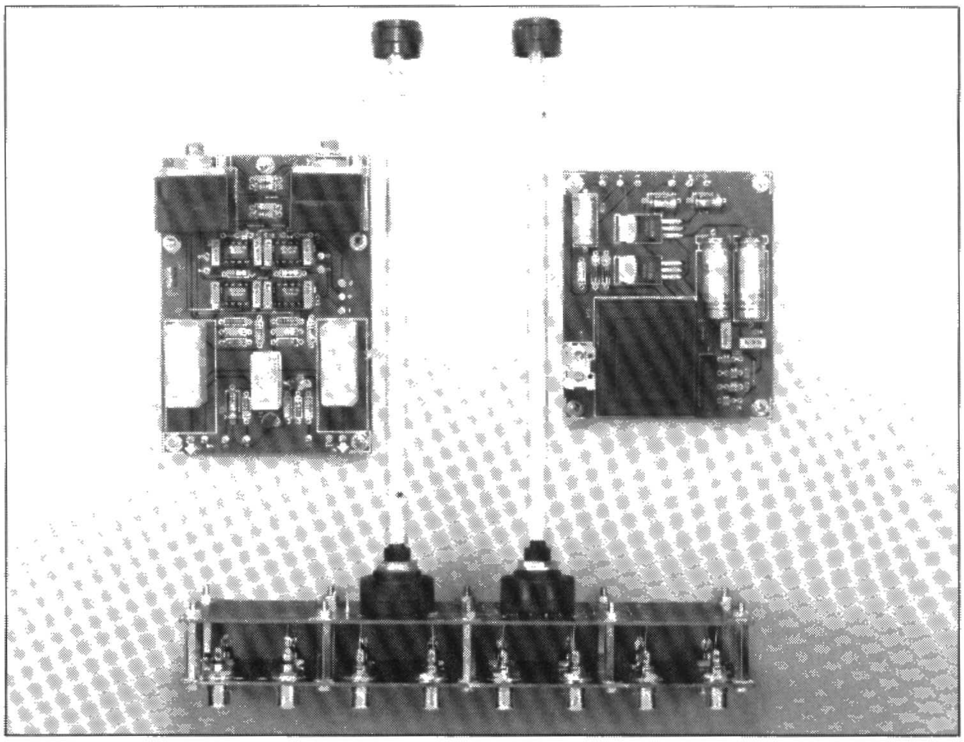
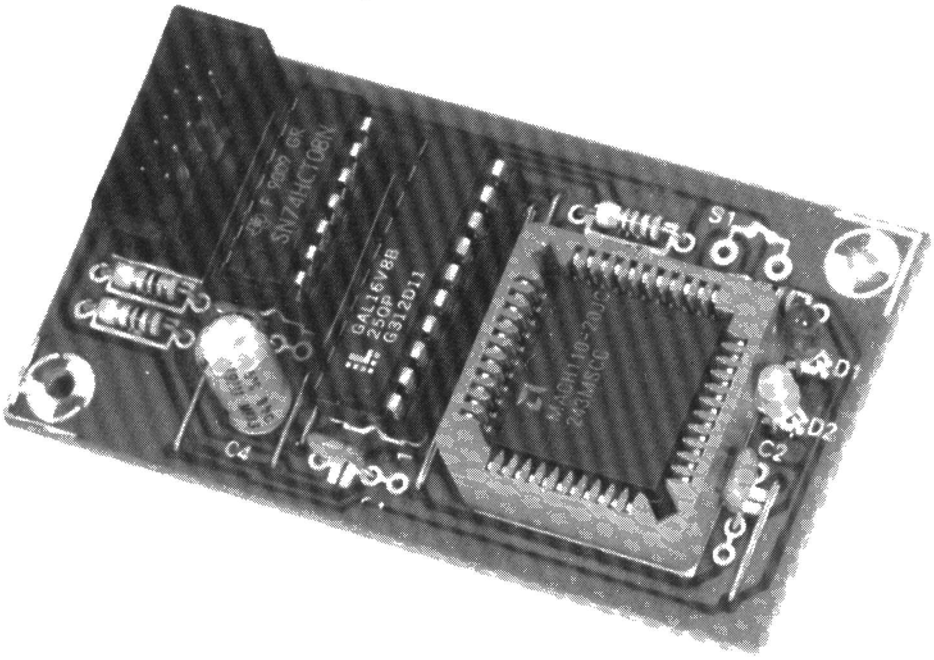


Fig. 8. The spindles of S_1 and S_2 must be extended to protrude through the front panel.

COPYBIT ELIMINATOR

By H.J. Schaake



WARNING. The circuit described in this article is intended solely for the recording, processing and copying of private musical work. The Editor and Publishers disclaim all responsibility for its use that infringes any copyright vested in commercial compact discs and (digital) cassettes.

This article describes an inexpensive and straightforward circuit for eliminating the copybit from a digital S/PDIF* audio signal. It enables any existing or future digital audio-signal source to be copied digitally time after time after time to any other digital audio recording system. In other words, with it one can copy (digitally) one's own musical work many times without degradation by the Serial Copy Management System—SCMS.

Over the past few years, more and more digital audio recording apparatus has become available: first, the DAT (Digital Audio Tape) recorder which was soon followed by DCC (Digital Compact Cassette) and Mini-Disc equipment. To meet the music industry's demand that copying of proprietary recordings (tapes, CDs, etc) should be difficult (in view of the menace of pirate copying), manufacturers of commercial digital recording equipment build in their apparatus a subsystem that enables making a digital copy once only. No further digital copies can be made from that copy, only analogue ones. This copy inhibit system is called Serial Copy Management System (SCMS). The system works with the aid of a bit, called the copy prohibit bit, which is contained in the serial digital audio signal. This is, of course, an excellent protective measure for the music industry, but it creates difficulties when one wants to make digital copies of one's private work. It is interesting to note, by the way, that most professional apparatus is not equipped with SCMS: such equipment thus makes unlimited digital copying possible.

It is clear that where the rights of the musical recording(s) are privately owned, there can be no objection to making as many digital copies as needed. For such cases, the circuit described may be built into the digital recorder to eliminate the copy prohibit bit.

The S/PDIF signal

The S/PDIF provides a serial single-line connection in one direction for transporting a digital stereo audio signal with associated sub-codes and error detection. The connection may be by coaxial or optical fibre cable.

Since it is a one-way serial connection and the receive circuit must 'know' where each bit begins and ends, the signal must contain a clock. As illustrated in **Fig. 1**, this is achieved by biphase mark encoding of all data. A '1' is coded as a whole square-wave period ($T = 1/\text{bitrate}$) and a '0' as a half square-wave period ($T = 2/\text{bitrate}$). Typical of this method is that at each and every bit edge a change of level takes place. This means that a special phase-locked loop—PLL—circuit can derive a bitrate synchronous clock from the signal. At the same time, it is, of course, useful if the receive circuit knows what each bit represents. Is it a sub-code bit? And, if so, which? Or is it an audio bit? If so, is it an MSB, and LSB, or in between? To give answers to such questions, the biphase coding protocol is suitably annotated at the first four bits of every 32-bit subframe.

Figure 2 shows the format of a subframe. Bits 0–3 form a preamble that may have one of three different forms : X, Y or Z—see **Fig. 3**. An X-preamble is the beginning of subframe A and a Y-preamble the beginning of subframe B—see **Fig. 4**. Together, subframes A and B form a frame of which 192 are contained in a block. The start of a block is marked by making subframe A0 begin with a Z-preamble instead of the usual X-preamble,

Bits 8–27 are 20 audio bits with the LSB as first bit. Bits 4–7 are either auxiliary data such as speech or four additional audio bits. Bit 28 is a validity bit that indicates whether the audio sample in the subframe is suitable for conversion to an analogue audio signal. Bit 31 is used as an even-parity check, that is, a simple error detection. Bits 29 and 30 are components of the subcode data. The subcode is transmitted by one bit per frame in Channel A as well as in Channel B. The 192 bits transmitted in each block form a complete subcode block that is repeated every 192 frames.

Bit 29 is used as user data block. It has no fixed definition and may be used freely

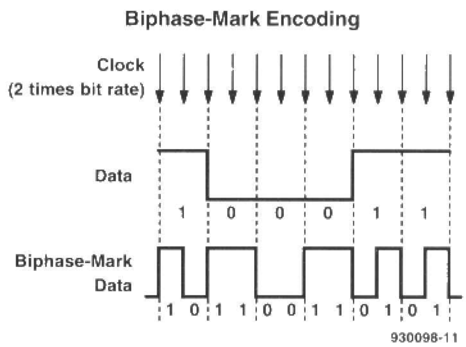


Fig. 1. Before their transmission, digital data are converted into a biphase format.

*Sony/Philips Digital Interface Format—the consumer version of the AES/EBU standard. This standard was devised by the American Audio Engineering Society and the European Broadcasting Union to define the signal format, electrical characteristics and connectors to be used for digital interfaces between professional audio products.[Editor]

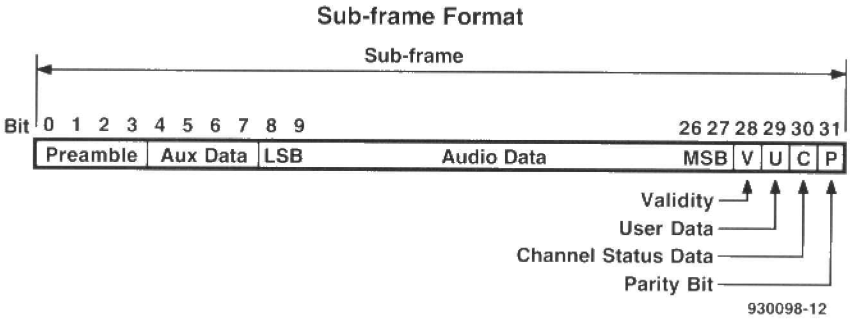
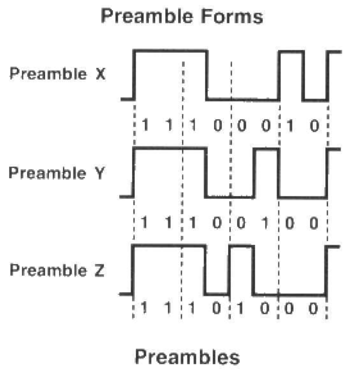


Fig. 2. Format of a sub-frame



	Biphase Patterns	Channel
X	11100010 or 00011101	Ch. A
Y	11100100 or 00011011	Ch. B
Z	11101000 or 00010111	Ch. A & C.S. Block Start

930098-13

Fig. 3. The preamble of a sub-frame may have one of three forms which indicate the start of a channel and a block.

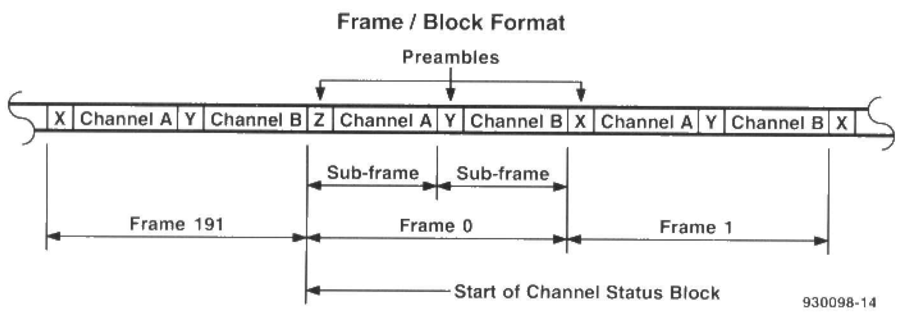


Fig. 4. A complete block is composed of 192 frames, each of which consists of a sub-frame A and a sub-frame B.

by the manufacturer for any application. Bit 30 is responsible for the channel status block. Note that channel status blocks A and B are identical.

The S/PDIF signal has a channel status block with consumer format: **Fig. 5** shows what the bits represent. For the present purposes only bit 2 of byte 0, the copybit, is of importance. Strictly speaking, so is bit 7 of byte 1, since this indicates the generation status. It is used to ensure that a private analogue recording on DAT can be copied digitally once. However, once the copybit has been deactuated, the generation status bit plays no role.

The present circuit checks whether the copybit is set (logic 0) or not (logic 1). If it is 0, it is made 1; but if it is 1 already, nothing happens. It is of interest to know that the copybit needs to be altered only once. From then on, any digital recording can be copied again and again by anybody on any equipment.

Block schematic and timing diagram

The block schematic is given in **Fig. 6** and the timing diagram in **Fig. 7**. The S/PDIF signal is applied to RXIN. The input selector, operated by the ON/OFF or UNLK signal determines whether the S/PDIF signal is applied to the circuit or not. The clock derived from the S/PDIF signal by the mother equipment is set on to the FCK line. The clock frequency is twice the bit rate and shifts all biphase-coded bits into an 8-bit shift register. Those eight bits enable the preamble detector to identify all X-, Y- and Z-preambles. As soon as preamble Z (QZ) is detected, the preamble counter is reset and two Y-preambles (QY) and two X-preambles (QX) are counted down, because the copybit is located in bit 30 of subframes 2A and 2B. Having arrived at subframe 2A, the preamble counter starts the bit counter by making the BCE signal logic high. Thereupon, the bit counter counts 52 clock periods and then makes the Copy Control Bit (CCB) high for one clock period. A clock period later, the Parity Control Bit (PCB) is made high for one clock period in an identical manner. Since the copybit is contained in both channels, the CCB and the PCB in subframe 2B are also made high for one clock period in the manner described. Note that the CCB is high during the 'second half' of the copybit, whereas the PCB is high during the 'first half' of the parity bit. The exact location of the copybit in both Channel A and Channel B is now known. The function of the CCB and the PCB will be reverted to later.

Register 1 functions as a D-type bistable with inverted input and delays the S/PDIF signal by one clock period. If the output of Register 1 is denoted DEL, then in Boolean algebra:

DEL = SPDIFIN>

Register 2 also functions as a D-type bistable but with selective logic at the D input. Whether the copybit is set or not may be ascertained from input signals SPDIFIN, CCB and DEL. In Boolean algebra:

NCA = SPDIFIN · DEL · CCB
+ SPDIFIN> · DEL> · CCB

Remember: the copybit is set when it is 0 (logic low) and a 0 coded in biphase results in a half period of a rectangular waveform with T = 2/bit rate. The FCK clock frequency amounts to twice the bit rate. For example, in the top signal, SPDIFIN, in **Fig. 8**, Case 10(A), it is clear that the copybit (indicated by C) has not been set because its first half is low and the second half is high. In other words, it is a whole period of a rectangular waveform with T = 1/bit rate and that corresponds to 1 (logic high).

As mentioned before, the CCB is high during the second half of the copybit. At that instant, DEL represents the inverted level of the first half and S/PDIF the second half. The first half is compared with the second half of the biphase-coded copybit: since the halves are not identical, output NCA of Register 2 becomes high a clock period later. NCA being high means that the copybit was not set.

The block Port in **Fig. 6** is a port without a register function. It is the last and most important link which ensures that the copybit is cleared if it was set; the parity bit is then also corrected. **Figure 8** shows all possible combinations of the biphase coded copybit/parity bit section that may occur in the SPDIFIN input signal, and the result at the Port output SPDIFOUT. The combinatorial function that arranges this is in Boolean algebra:

SPDIFOUT = SPDIFIN · CCB> · PCB
+ DEL · CCB + DEL> · PCB · NCA>
+ SPDIFIN · PCB · NCA

From a design point of view, it would be neater if Port were a register function, because theoretically glitches may arise dur-

ing the active edges of the clock in the middle of the copybit and parity bit of each subframe 2A and 2B. In the prototype, no glitches were detected. Even if they had been, they would not have mattered much, because the S/PDIF receive circuit reacts to the signal between two active FCK edges, since that is taken to be more stable.

The SPDIFOUT signal from which the copybit has been eliminated is applied via the output selector to RXOU, from where it is passed directly to the S/PDIF input of a DCC or DAT recorder.

Since there is no register in the entire S/PDIF path and the copybit eliminator board is built into the mother equipment (but see 'Building in' later on), there is no additional PLL required to derive the FCK signal. This arrangement saves a lot of circuitry. There is also no need for an additional power supply, because the power drain is so small that the mother equipment can supply it.

To guarantee sure starting of the receive PLL, an additional switch input has been provided: UNLK. This provides the RX PLL signal that is found in all equipment with an S/PDIF receive circuit. It indicates whether the PLL generates a bit rate synchronous clock. If this is not so, the UNLK

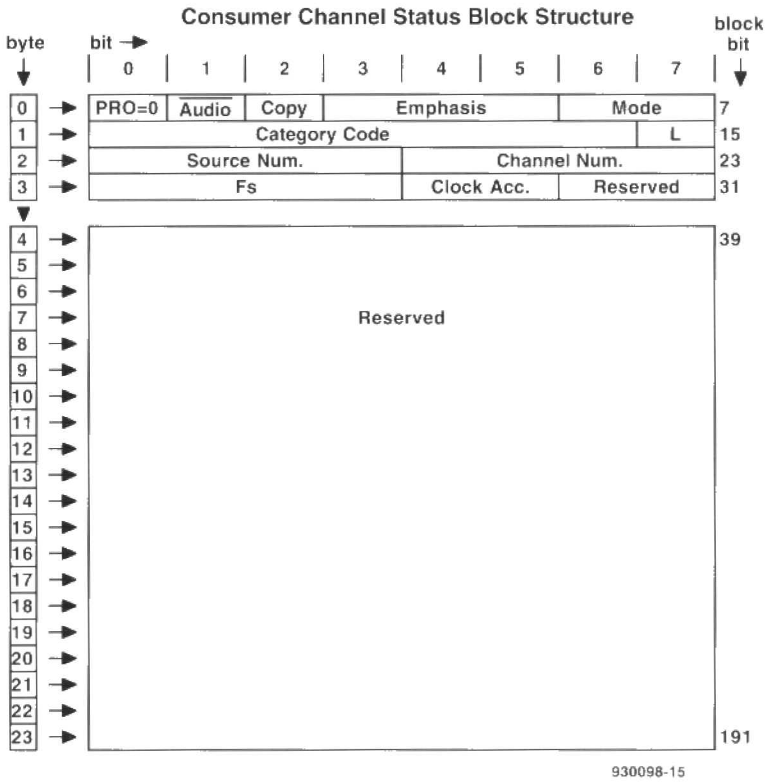


Fig. 5. The significance of the bits in the data block.

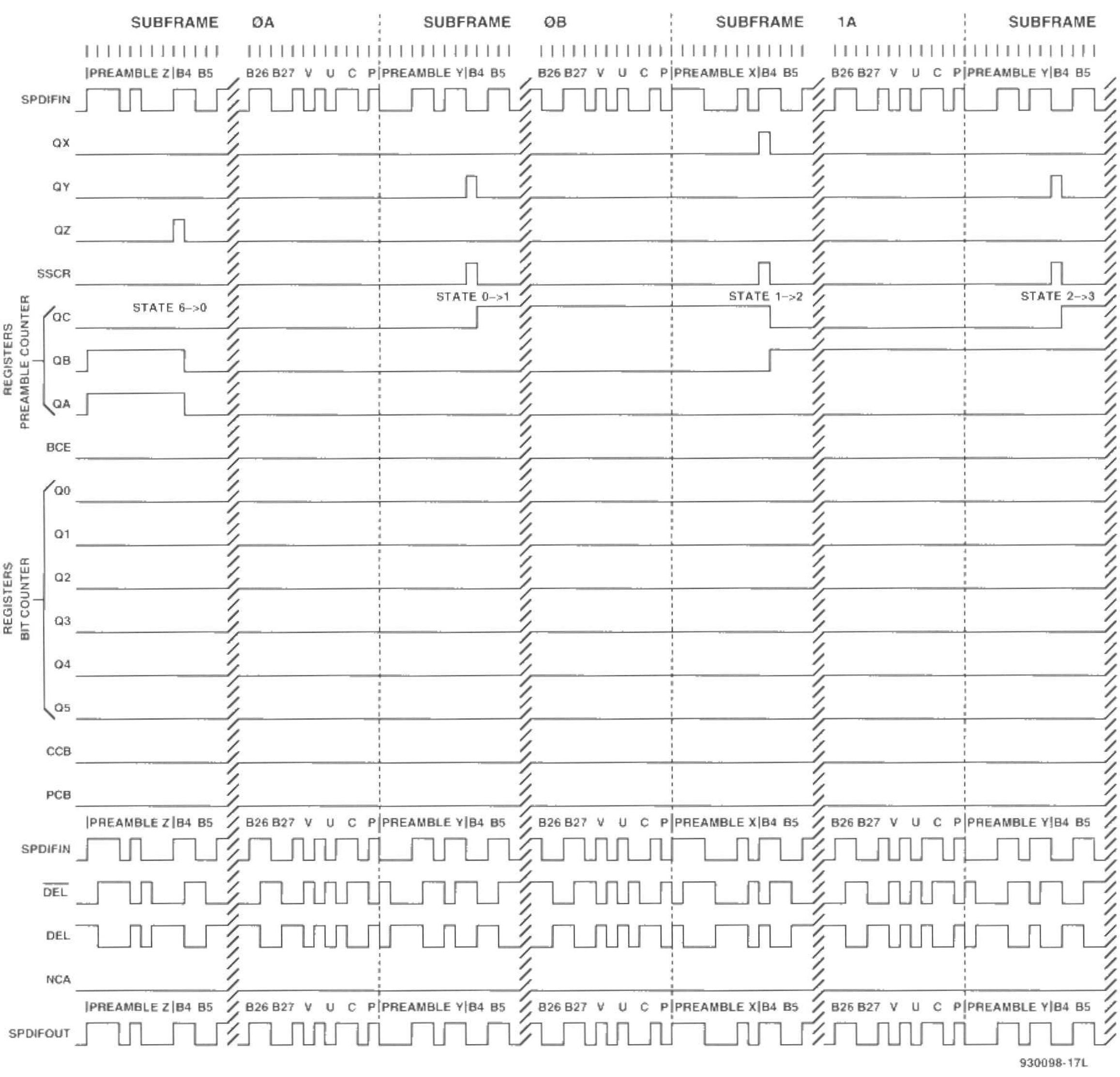


Fig. 7. This extensive timing diagram clarifies the

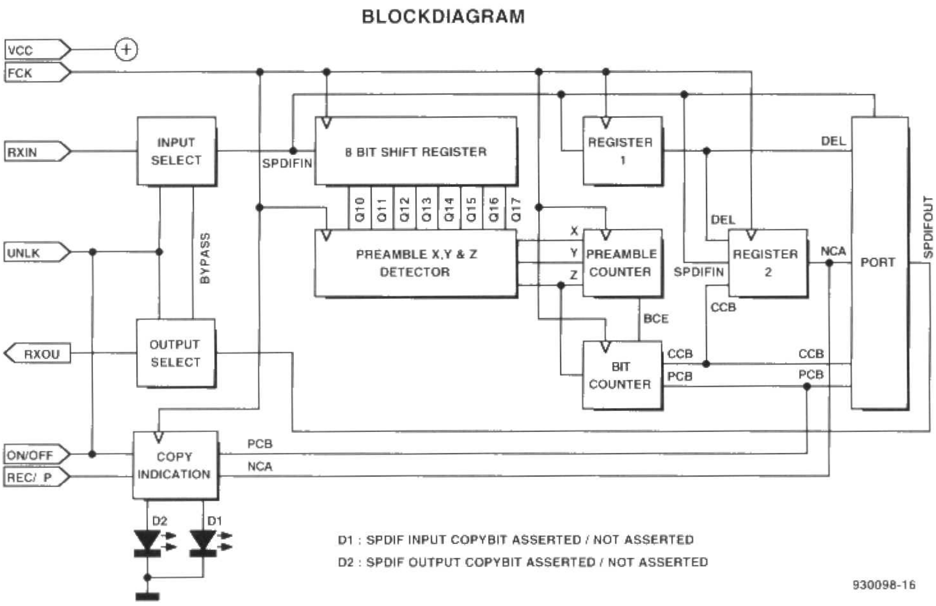


Fig. 6. Block diagram of the copybit eliminator

signal is assumed to be low and the copybit eliminator is then temporarily bypassed. As soon as UNLK becomes high, the PLL is locked. When signal ON OFF is low, the S/PDIF signal is applied to the eliminator and filtering commences

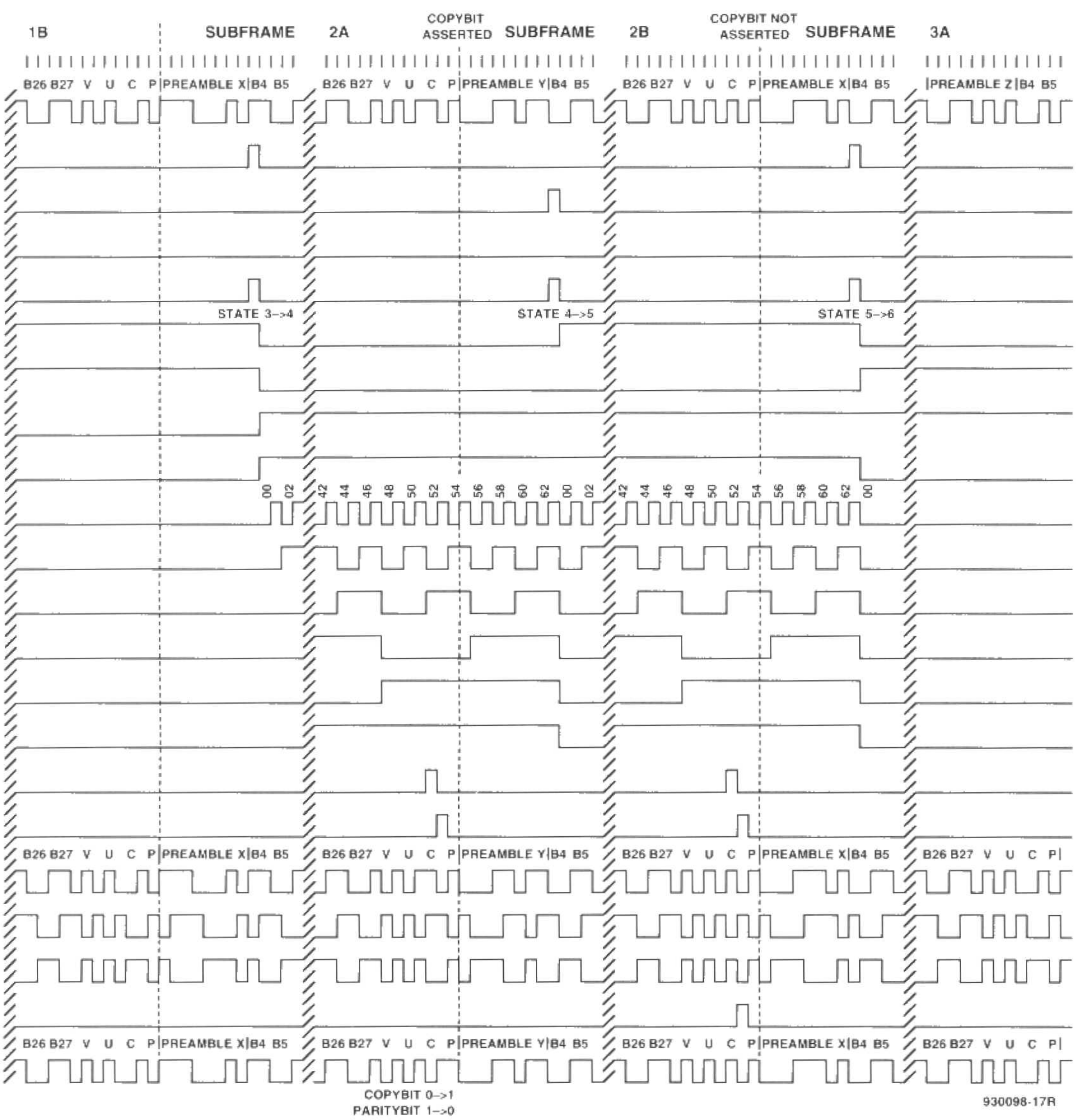
Copy indication is a copybit monitoring function which drives two LEDs. The input LED is on if a set copybit is present in the input signal. The output LED is on if a set copybit is present in the output signal. Normally, when the eliminator is operating, the input LED is on and the output LED is off.

The circuit

The LED indications are only true during recording and it is, therefore, necessary to take the record indication line from the mother equipment and connect this to REC/P. The LEDs can light only when REC/P is high.

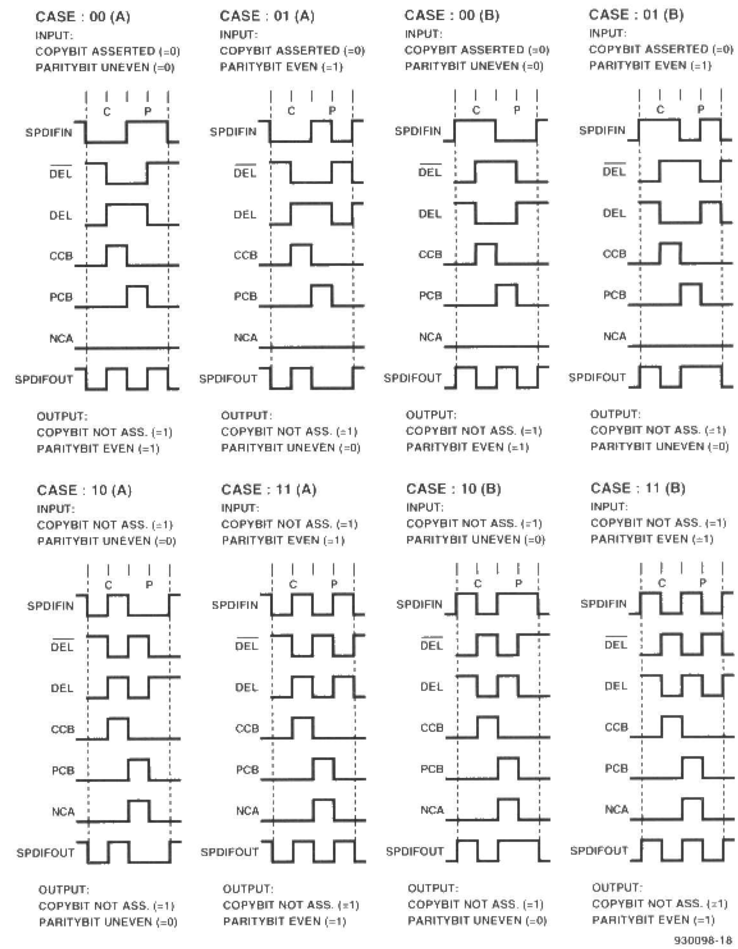
All signals required for proper operation of the circuit pass via K_1: the umbilical cord to the mother equipment.

Circuit IC_1 is a GAL/PAL Type 16V8, while IC_2 may for many readers be an unfamiliar logic building block: Type MACH110 from AMD. The MACHXXX is a new family whose members function somewhere between a PAL and an FPGA/EPLD/gate array. The MACH110 is roughly equivalent to 3× a 22V10 GAL with an integral separately programmable connection matrix.



signal path in the block diagram in Fig. 6.

Fig. 8. All possible combinations of the copybit/parity bit part that may ocvcur in the SPDIFIN input signal and the result at Port output SPDIFOUT.



The LEDs are controlled by the four gates of a 74HCT08.

The eliminator can be switched off with S_1, which connects pin 13 of IC_{3d} to +5 V. When the switch is open, R_3 ensures that the eliminator is on automatically.

Construction

The eliminator is best built on the PCB in **Fig. 10**, which, together with the two programmed ICs (IC_1 and IC_2), is available ready made (see page 70). The MACH110 is housed in a PLCC case. One of the four corners of the IC is slightly flattened to show how the device should be located on the board. It should be mounted in a special socket to obviate any intricate soldering direct to the device.

K_1 is a 10-pin box header, so that the circuit can be conveniently connected to the appropriate points in the recorder via a length of flatcable.

Finally, if use of S_1 is not foreseen, this switch may be omitted.

Building in

The eliminator is intended to be built into the mother equipment, for example, a DAT recorder. The necessary connections are made with a length of flatcable: those for five of the more popular recorders are given in Table 1. The following signals should be applied to the pins of K_1 as follows:

1. (FCK): $128f_S$, that is, 128× the sample frequency clock. If the eliminator does not function properly and all other connections are found to be all right, delay the FCK signal with the aid of a 150 Ω resistor or invert it.
2. (UNLK): the PPL lock indication. This signal must be low when the PLL is locked. If it is high, invert it or do not use the signal, in which case the pin should be linked to earth.
3. (RXOU): break the relevant track on the board behind the coaxial or optical S/PDIF input buffer. Connect the part of the track from the input buffer to RXIN and the other part to RXOU.
4. (RXIN): see instructions for pin 3.
5. (REC/P): the record indication signal; this is high when the mother equipment is recording.
6. (V_{cc}): the +5 V supply line from the mother equipment.
7. (GND): the digital earth of the mother equipment.
8, 9, 10. These are the LED connections

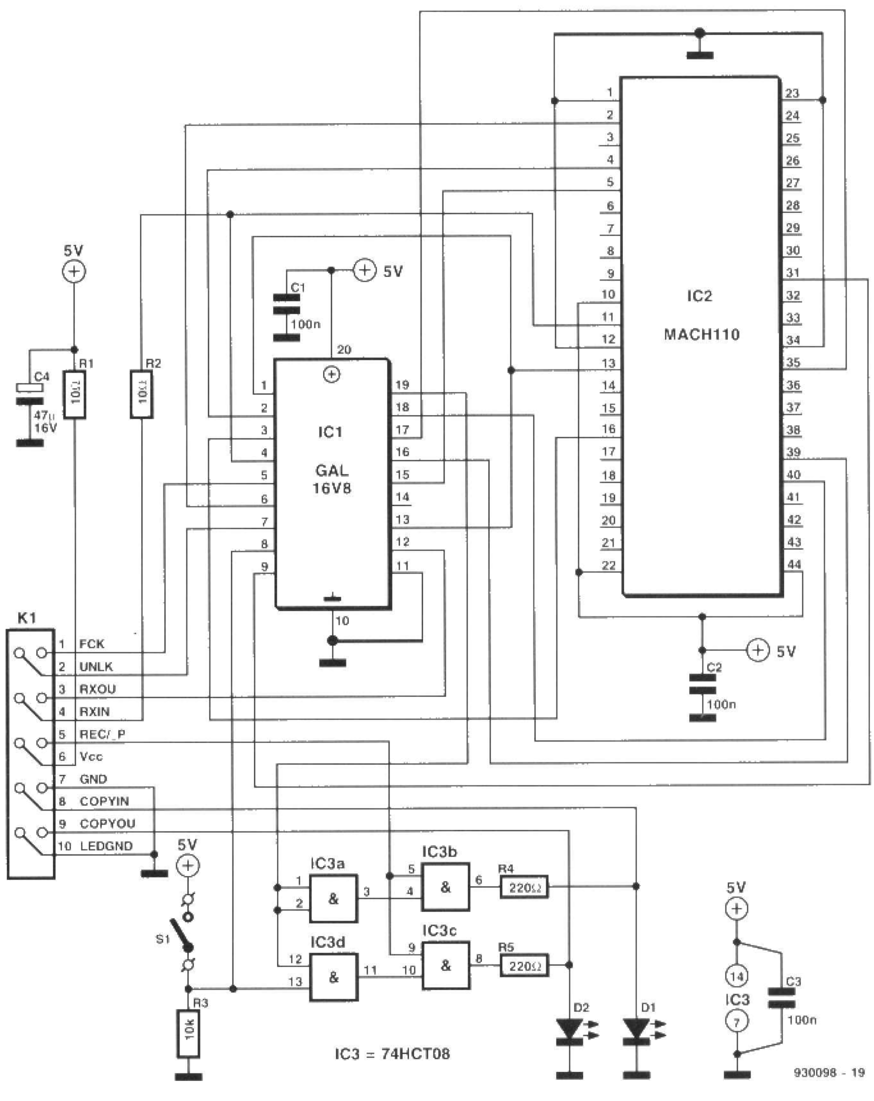


Fig. 9. Circuit diagram of the copybit eliminator.

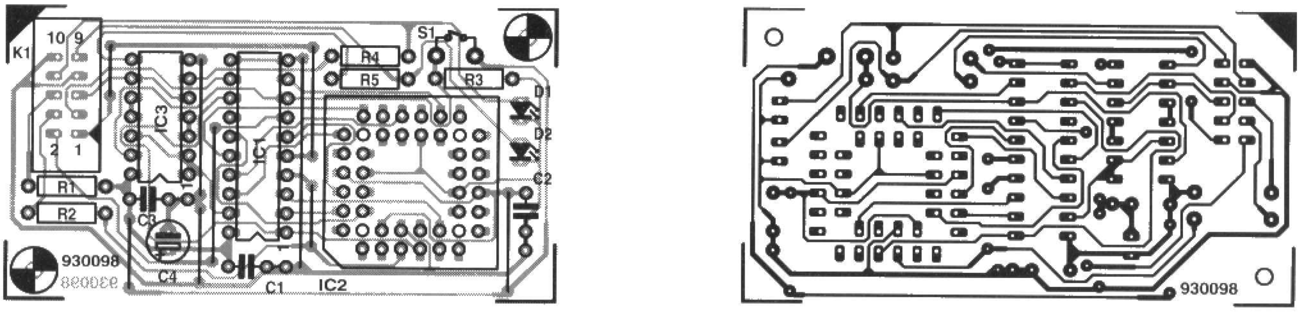


Fig. 10. The PCB for the copybit eliminator is small enough to be built into the mother equipment.

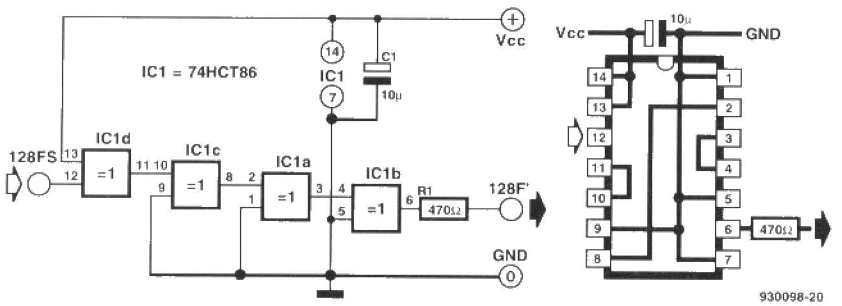


Fig. 11. Auxiliary circuit for use with Type XD-Z505 DAT recorder from JVC.

K_1 pin no.	Signal in recorder	IC/pin in recorder	Remarks
Denon DTR-2000			
1	CKI0128	351/8	
2	DUNLOK	351/93	
3	RX	351/23	
4	---	305/6	break track
5	---	not known	
6	+5 V	604/3	
7	D GND	604/2	
JVC XD-Z505			
1	128F'	401/13	
2	UNLOCK	401/62	
3	RX0	401/35	coaxial
3	RX1	401/34	optical
4	---	406/1	break track (coaxial)
4	---	406/13	break track (optical)
5	+5 V (D)	emitter Q21	
6	+5 V (D)	emitter Q21	mount heat sink on IC
7	G (D)	chassis	
JVC XD-Z1010			
1	128F	501/5	
2	UNLK	501/46	
3	RX	501/51	
4	---	372/11	break track
5	---	not known	
6	5 V (D)	03/3	
7	G (D)	03/2	
Sony DTC 55ES & DTC 57ES			
1	F128	307/58	
2	UNLK	307/31	
3	RX	307/52	
4	RX	301/8	break track
5	Q2>	309/8	
6	+5 V	322/3	mount heat sink on IC
7	GND	chassis	

if D_1 and D_2 are desired to be located away from the eliminator board.

Most PLLs in an S/PDIF receive circuit generate a frequency that is twice or four times as high as the clock frequency. Fortunately, the generated frequency is scaled down synchronously, so it is always possible to find a clock of $128f_s$. However, the S/PDIF-PLL of the JVC Type XD-Z505 DAT recorder generates a clock of $384f_s$, which is scaled down by 3. Although this results in a clock of $128f_s$, the leading edge of it is no longer at the centre (that is, the duty factor is not 50%). This is a small problem, however, which is easily remedied by delaying the clock with the aid of four HC gates as shown in **Fig. 11**.

Note that usually the warranty on the mother equipment is invalidated if any modification is carried out. It is for the constructor to decide whether the building in of the eliminator is worth that or whether to wait until the warranty has expired.

Parts list

Resistors:
R_1, R_2 = 10 Ω
R_3 = 10 kΩ
R_4, R_5 = 220 Ω

Capacitors:
C_1–C_3 = 100 nF
C_4 = 47 µF, 16 V, radial

Semiconductors:
D_1 = LED, 3 mm, red
D_2 = LED, 3 mm, green

Integrated circuits:
IC_1 = 16V8 (Ref. 6321, see p. 70)
IC_2 = MACH110 (Ref. 6321, see p. 70)
IC_3 = 74HCT08

Miscellaneous:
K_1 = 10-way straight box header
S_1 = switch with make contact
PCB Ref. 930098 (see p. 70)

Table 1. Connections between K_1 and the relevant circuits in various mother equipment.

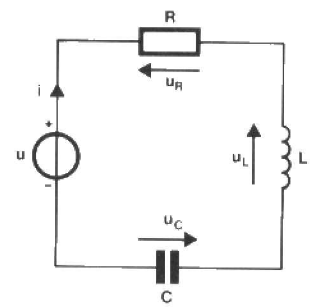
FIGURING IT OUT

PART 13 – SECOND-ORDER MODELS

By Owen Bishop

This series is intended to help you with the quantitative aspects of electronic design: predicting currents, voltage, waveforms, and other aspects of the behaviour of circuits. Our aim is to provide more than just a collection of rule-of-thumb formulas. We will explain the underlying electronic theory and, whenever appropriate, render some insights into the mathematics involved.

Last month we examined ways of using first-order differential equations to build circuit models. This month we extend the methods to include second-order equations. These allow us to model circuits of greater complexity, such as that in **Fig. 110**.



930010-13-12

Fig. 110

This includes resistive, inductive and capacitive elements. By Kirchhoff's Voltage Law:

$$u_L + u_R + u_C = u.$$

As we did last month, we use lower-case letters for quantities which are inherently variable in time and capitals for constants. Substituting equivalent expressions for the voltages, based on Eq. 26 of Part 4, Ohm's law, and Eq. 19 of Part 4:

$$L\frac{di}{dt}+Ri+\frac{q}{C}=u$$

We will restrict the analysis to situations in which u is constant, hence $du/dt = 0$. Then, differentiating both sides of this equation:

$$L\frac{d^2i}{dt^2}+R\frac{di}{dt}+\frac{i}{C}=0$$

In differentiating the third term, use $q = it$, and therefore $dq/dt = i$. The term d^2i/dt^2 makes this a second-order equation. Divide through by L to make unity the coefficient of the first term:

$$\frac{d^2i}{dt^2}+\frac{R}{L}\cdot\frac{di}{dt}+\frac{1}{LC}\cdot i=0 \quad \text{[Eq. 94]}$$

Equation 94 models the circuit. It now remains to solve it and substitute actual values of R, L and C.

Auxiliary equation

For an equation of the form of Eq. 94, in which R, L and C are constants, there is an **auxiliary equation** of the form:

$$m^2 + fm + g = 0, \quad \text{[Eq. 95]}$$

in which f is the coefficient of di/dt and g is the coefficient of i. In Eq. 94, $f = R/L$ and $g = 1/LC$. Solving Eq. 95 (a straightforward quadratic equation) for m is much easier than solving Eq. 94 for i. With values of f and g substituted in Eq. 95:

$$m^2+\frac{R}{L}m+\frac{1}{LC}=0 \quad \text{[Eq. 96]}$$

This is solvable by applying the well-known quadratic formula which, when applied to Eq. 95, is:

$$m=\frac{-f\pm\sqrt{f^2-4g}}{2}$$

The value of the expression f^2-4g (known as the **discriminant**, D) determines what kind of solution the equation has:

If D is positive, the equation has two real roots.

If D is zero, the equation has two equal roots.

If D is negative, the equation has two imaginary roots.

If D is positive, the two real roots are m_1 and m_2 and the solution to Eq. 94 is:

$$i=Ae^{m_1t}+Be^{m_2t} \quad \text{[Eq. 97]}$$

If D is zero, the roots are both m and the solution to Eq. 94 is:

$$i=Ae^{mt}+Bte^{mt} \quad \text{[Eq. 98]}$$

If D is negative, we calculate $k = \sqrt{(-D/2)}$ and the solution is:

$$i=Ae^{-ft/2}\cos kt+Be^{-ft/2}\sin kt \quad \text{[Eq. 99]}$$

All three equations are general solutions (see Part 12) and have two arbitrary constants, A and B. Last month we had just one such constant and needed one border condition in order to find the particular solution. There are two constants, and we need two border conditions for second-order equations.

Worked example

Given $R = 500\,\Omega$, $L = 100$ mH and $C = 2\,\mu$F: $f = R/L = 500/100\times10^{-3} = 5000$; and $g = 1/LC = 1/100\times10^{-3}\times2\times10^{-6} = 5\times10^6$. From these values of f and g:

$$D = f^2 - 4g = 5000^2 - 20\times10^6 = 5\times10^6.$$

This is positive, so the equation has two real solutions:

$$m_1=\frac{-f+\sqrt{D}}{2}=\frac{-5000+2236}{2}=-1382$$

$$m_2=\frac{-f-\sqrt{D}}{2}=\frac{-5000-2236}{2}=-3618$$

Substituting in Eq. 97:

$$i=Ae^{-1382t}+Be^{-3618t} \quad \text{[Eq. 100]}$$

This is the general solution. We can apply this to any set of border conditions. We can imagine the voltage fluctuating, perhaps regularly, perhaps irregularly, causing a varying current in the circuit. Then, when $t = 0$, the voltage is suddenly held constant (Eq. 94). The models tells what happens after that. For this example, suppose that the current is 2 mA wen timing begins, or $i = 2\times10^{-3}$ when $t = 0$. Also assume a second border condition that the rate of change of current, di/dt, is 0.05 As^{-1} when $t = 0$. With t equal to zero, e has zero index in both terms and so equals unity. Substituting the values for the first border condition in Eq. 100:

$$2\times10^{-3} = A + B$$

$$\therefore\ B = 0.002 - A.$$

Substitute this value for B in Eq. 100:

$$i=A(e^{-1382t}-e^{-3618t})+0.002e^{-3618t} \quad \text{[Eq. 101]}$$

To incorporate the effect of the second border condition into the equation, we must first differentiate (see Part 5) Eq. 101 to obtain an equation for di/dt:

$$\frac{di}{dt}=A(-1382e^{-1382t}+3618e^{-3618t})-7.236e^{-3618t} \quad \text{[Eq. 102]}$$

If $di/dt = 0.05$ when $t = 0$:

$$0.05 = A(-1382 + 3618)-7.236.$$

$A = (0.05 + 7.236) / 2236$
$=0.003258.$

Substituting this in Eq. 101:

$$i=0.003258(e^{-1382t}-e^{-3618t})+0.002e^{-3618t}$$

Rearranging terms gives:

$$i=0.003258e^{-1382t}-0.001258e^{-3618t}$$

[Eq. 103]

This is the particular solution and **Fig. 111** shows its graph. It shows that at $t = 0$ the current is 2 mA, as specified. The increase of current when $t = 0$ is too small to show on this graph. The tangent to the curve at this point would slope up to the right by only 3.6°. This upward slope is almost instantly countered by the relatively strong damping effects of capacitance and inductance. By the end of the third millisecond, the current has been almost entirely damped out.

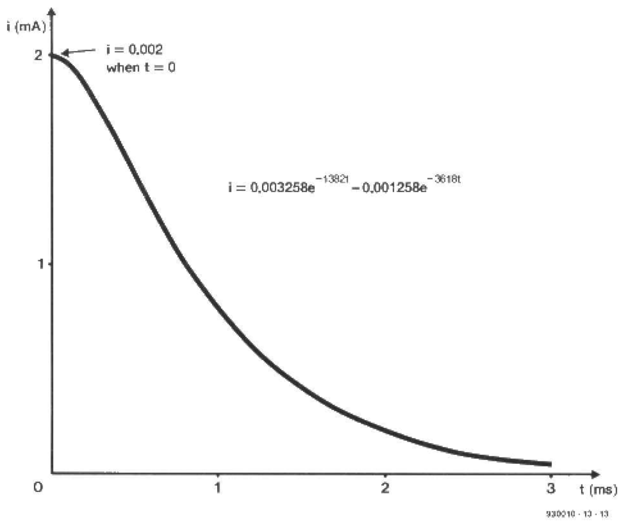


Fig. 111

Figure 112 shows what happens if we keep the first border condition unchanged, but have the current increasing at 2 A s^{-1}, instead of at only 0.005 A s^{-1}. Substituting di/dt in Eq. 102:

$A = (2 + 7.236) / 2236 = 0.004131.$

From Eq. 101:

$$i=0.004131e^{-1382t}-0.002131e^{-3618t}$$

We have another particular solution, matching the new border conditions. Its graph (**Fig. 112**) shows current continuing to increase, to about 2.12 mA, before damping takes effect. From the equations we have established, we can calculate the current and the rate of change of current at any instant from $t = 0$ onwards. With this information, we can go on to calculate the voltage across the components, and quantities such as the charge on the capacitor and the magnetic linkage of the inductor at any time.

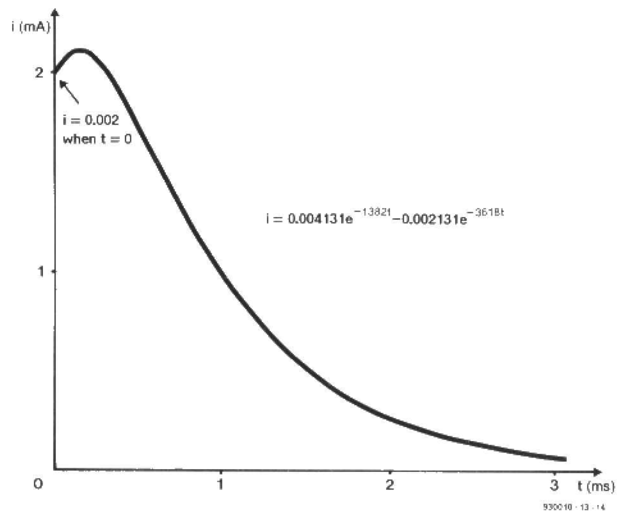


Fig. 112

Specifying later current

Border conditions need not be restricted to events occurring when $t = 0$. We can specify i or di/dt at any other instant after timing begins. It makes the equation slightly more complicated, because there is no simplification of the equations due to the index of e being zero. Let us try the same circuit, with the same first border condition, but the second border condition being that $i = 0.003$ when $t = 0.001$. We are saying that the current increases to a definite value in a specified time. Since we have specified i, not di/dt, we go back to Eq. 101 and proceed from there. Substitute the second border condition into this, which involves multiplying the indices by 0.001:

$$0.003=A(e^{-1.382}-e^{-3.618})+0.002e^{-3.618}$$
$$=0.2242A+5.3673\times10^{-5}$$
$$\therefore\ A=0.01314$$

Substituting the new value of A into Eq. 101:

$$i=0.01314(e^{-1382t}-e^{-3618t})+0.002e^{-3618t}$$
$$=0.01314e^{-1382t}-0.01114e^{-3618t}$$

Yet another solution, with the graph shown in **Fig. 113**. Current increases even further before damping takes effect.

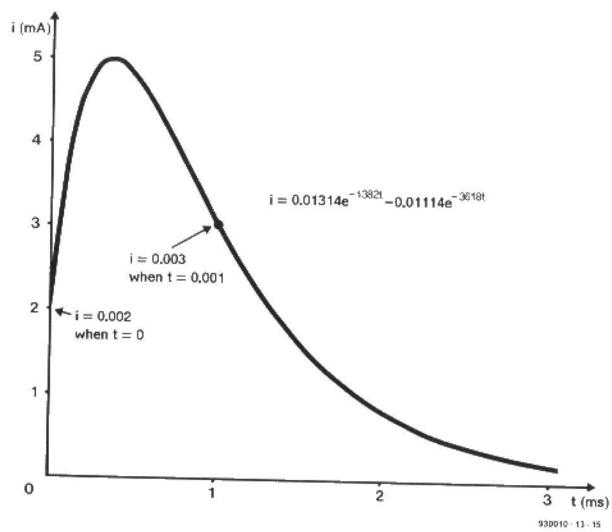


Fig. 113

Critical damping

The curves we have seen so far represent overdamping of the current. Current is reduced to zero fairly promptly. The model can be used also to investigate the circuit behaviour when it is critically damped. We reduce the capacitance slightly, to 1.6 µF, leaving R and L as before and, for comparison with **Fig. 113**, keep the same pair of border conditions.

With the new value for C, f remains unchanged, but g becomes 6.25×10^6, and:

$$D = 5000^2 - 4\times6.25\times10^6 = 0.$$

With a zero discriminant, the solution of the auxiliary equation is

$$m = -f/2 = -5000/2 = -2500.$$

The general solution takes a different form (Eq. 98):

$$i=Ae^{-2500t}+Bte^{-2500t}$$

[Eq. 104]

Substituting the first border condition into this:

$$0.002 = A,$$

Eq. 104 becomes:

$$i = 0.002e^{-2500t} + Bte^{-2500t}.$$

Now substitute $i = 0.003$ and $t = 0.001$ into this:

$$0.003=0.002e^{-2.5}+0.001Be^{-2.5}$$

$$\therefore\ B = 34.55.$$

The particular solution is:

$$i = 0.002e^{-2500t} + 34.55te^{-2500t}.$$ [Eq 105]

The graph in **Fig. 114** shows current rising to a peak at 5.9 mA before being damped. The second border condition occurs on the way down.

Under-damping

This occurs when the discriminant has a negative value. For example, let us reduce the capacitance drastically, to 10 nF. The f remains at 5000, but g becomes 10^9 and D becomes -3.975×10^9. With a negative discriminant, we need to calculate k:

$$k = \sqrt{3.975\times10^9/2} = 44581$$

The general solution is given by Eq. 99:

$$i = Ae^{-2500t}\cos 44581t + Be^{-2500t}\sin 44581t$$ [Eq. 106]

Keeping to the same border conditions, applying the first condition to Eq. 106, and using the facts that cos 0 = 1 and sin 0 = 0:

$$0.002 = Ae^0 + 0$$

$$\therefore\ A = 0.002.$$

Substituting this in Eq. 106, together with the values for t and i under the second border condition:

$$0.003 = 0.002e^{-2.5}\cos 4.4581 + Be^{-2.5}\sin 4.4581$$

$$\therefore\ B = -0.03828$$

This leads us to the particular solution:

$$i = 0.002e^{-2500t}\cos 44581t - 0.03828e^{-2500t}\sin 44581t$$

The graph of this equation has an interesting form—**Fig. 115**. It shows the current reversin g many times with gradually decreasing magnitude. Oscillations of this type are typical of an under-damped circuit. The oscillations take about 1.5 ms to die away.

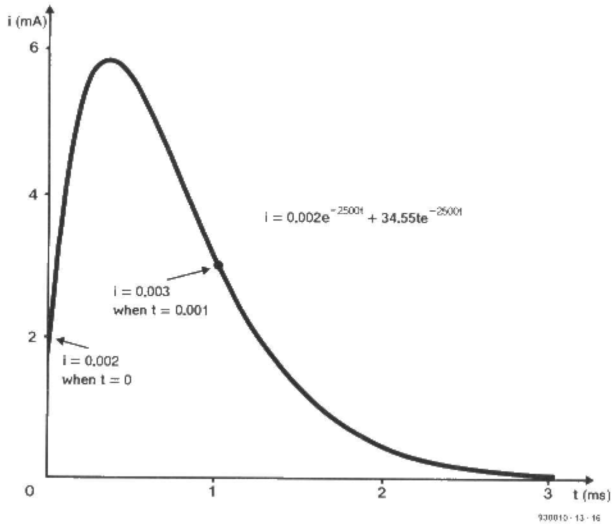


Fig. 114

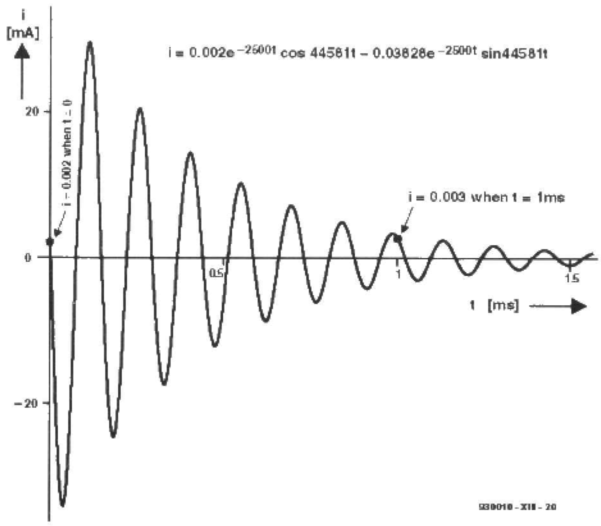


Fig. 115

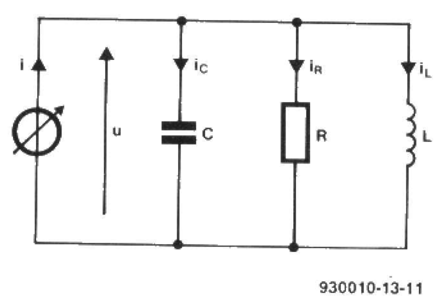


Fig. 116

Graphic calculator

A graph is an important aid to visualizing the behaviour of a model, and hence the behaviour of the circuit it is modelling. But plotting graphs is a tedious matter, particularly when equations contain several exponential terms. With over-dampled and critically-damped circuits, it is possible to sketch the shape of the graph roughly after calculating half a dozen points. But the oscillations of an under-damped circuit often need 30 or more points to produce a reasonably representative curve.

A computer graphics package may save a lot of time: the illustrations to this article were produced in this way. A graphic calculator produces results even more quickly. We used one when we were planning the values to use in the examples. To make graph plotting even quicker, program the calculator to accept variables, then to plot the graph.

The following is an example of a short program used on a graphic calculator to plot graphs of equations of the same type as Eq. 103: 'EXPO1':"A":?→A:"M1":?→C:"B":?→B:"M2":?→D:GRAPH Y=Ae–CX+Be–DX:. The program name is 'EXPO1'. The user is requested to key in values for A, m_1, B and m_2. As soon as the final value has been keyed in, the graph is plotted according to the equation in the program.

A program can also include commands to set the ranges of t and i for the displayed graph, so that the curve fills the screen reasonably well. If the range command follows the input of variables, one or more of these variables can be used in the range commands. For example, the range for i can be set to run from –2 A to +2 A. It is also possible to include inputs to set the range of t directly from the program. For those who like to play around with models, adjusting the values to produce the required results, a graphic calculator is a valuable tool.

Parallel circuit

Figure 116 shows a circuit with resistance, capacitance and inductance in parallel. Building the model follows very much the same sequence as building the model of the series circuit. By KCL:

$$i_C + i_R + i_L = i.$$

Replacing the currents by equivalent expressions:

$$C\frac{du}{dt} + \frac{u}{R} + \frac{N\varphi}{L} = i$$ [Eq. 107]

The third term on the right is obtained by noting that $L = N\varphi/i$, as in Eq. 22, Part 5, where φ is the magnetic flux and N is the number of turns in the coil. Differentiating Eq. 107, and assuming that i is constant:

$$C\frac{d^2u}{dt^2} + \frac{1}{R}\cdot\frac{du}{dt} + \frac{u}{L} = 0$$

In obtaining the third term, $d\varphi/dt = u/N$ (see Eq. 23, Part 5), so the term reduces to u/L. Dividing throughout by C gives the model equation:

$$\frac{d^2u}{dt^2} + \frac{1}{RC}\cdot\frac{du}{dt} + \frac{u}{LC} = 0$$ [Eq. 108]

The auxiliary equation is:

$$m^2 + m/RC + 1/LC = 0$$

in which $f = 1/RC$ and $g = 1/LC$. With given values of R, C and L, the discriminant may be positive, zero or negative, yielding equations for u having the same

form as Equations 97 to 99.

Here is an example of an under-damped circuit with $R = 1\ \text{k}\Omega$, $C = 10$ nF and $L = 18$ mH.

$RC = 1\times10^{-5}$, so $f = 1/RC = 10^5$ and $f^2 = 1/(RC)^2 = 1\times10^{10}$.

$LC = 1.8\times10^{-10}$, so $4g = 4/LC = 2.222\times10^{10}$.

From these we find that $D = -1.222\times10^{10}$ and $k = 78166$. The general equation is:

$$u = A\mathrm{e}^{-50000t}\cos 78166t$$
$$B\mathrm{e}^{\ 50000t}\sin 78166t$$

Now for some border conditions. When $t = 0$, $u = -1$; when $t = 0.0001$, $u = -0.5$. Using the first condition, remembering that $\cos 0 = 1$ and $\sin 0 = 0$:

$$-1 = A.$$

For the second condition:

$$-0.5 = -\mathrm{e}^{-5}\cos 7.8166$$
$$+B\mathrm{e}^{-5}\sin 7.8166$$
$$\therefore\ B = -74.22.$$

The particular solution is:

$$u = -\mathrm{e}^{-50000t}\cos 78166t$$
$$-74.22\mathrm{e}^{-50000t}\sin 78166t$$

The graph of this is shown in **Fig. 117**. It begins with a massive 'kick' of up to –34 A. After a few swings of rapidly diminishing amplitude, the current is fully damped out in about 0.15 ms.

These examples show what can be done when we make certain simplifying assumptions about the model. If these assumptions are not valid, in particular, if we can not assume that voltage or current is constant, the equations are more difficult to differentiate and pass beyond the scope of this series. However, there are ways around this difficulty, as will be explained next month.

Acknowledgment. The author would like to thank the Casio Computer Company Ltd for their valuable assistance.

Test yourself

1. Find the particular equation which models a series circuit (**Fig. 110**) in which $R = 1\ \text{k}\Omega$, $L = 200$ mH and $C = 100$ nF, given the border conditions that $i = -0.01$ when $t = 0$, and $i = +0.01$ when $t = 0.005$. Is the circuit over-damped, critically damped or under-damped? Find the current when $t = 0.0008$ s.

2. In another series circuit, $R = 5\ \text{k}\Omega$, $C = 22\ \mu$F and $L = 0.5$ H. When $t = 0$, $i = 0.1$ and $di/dt = 0.5$. Find the particular solution for this circuit. Find the current when $t = 0.5$ ms and when $t = 100$ ms. How long does the current take to fall to 0.01 A? (Plot a graph or solve the equation of di/dt by taking natural logs).

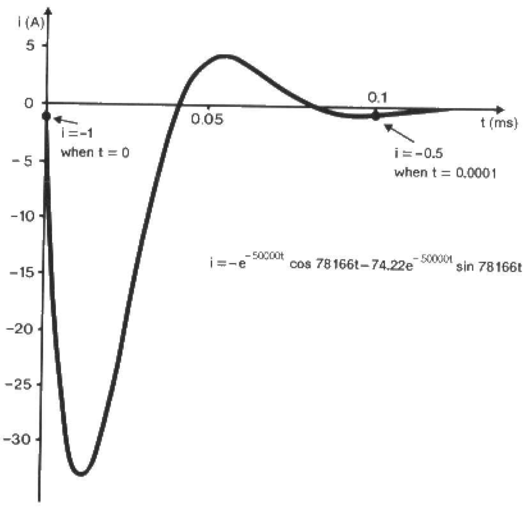


Fig. 117

Answers to Test yourself (Part 12)

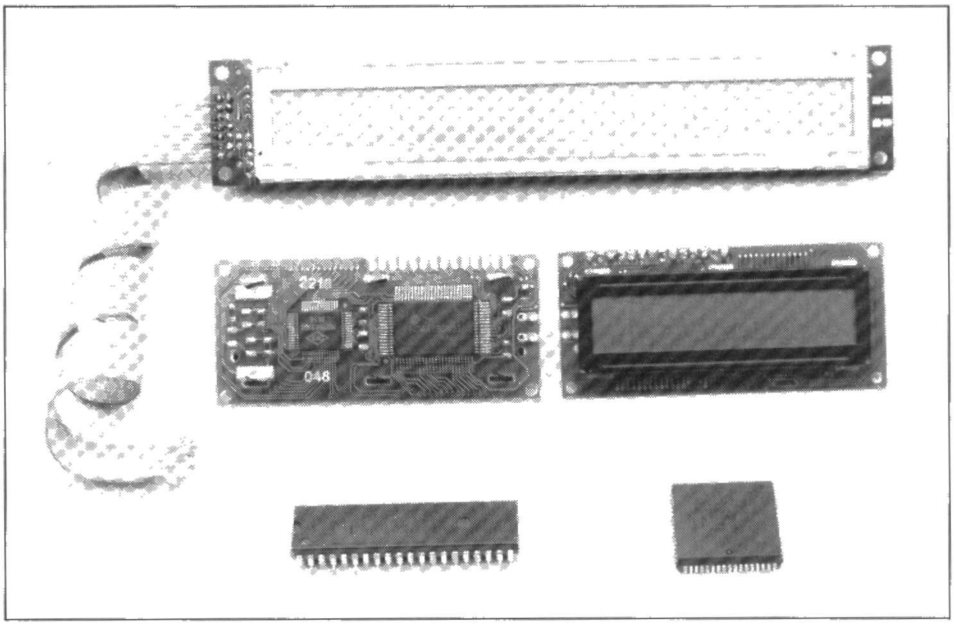
1. $q = 9\mathrm{e}^{-1.418t}\times10^{-4}$;
   (**a**): $u = 1.45$ V
   (**b**): $i = 74.9\ \mu$A.

2. 0.857 s.

3. 532 μA.

LIQUID CRYSTAL DISPLAYS

By M. Reichtomann



Liquid crystal displays are typified by the simplicity with which they can be controlled and accommodated in a circuit. This short article shows how these modules can be connected to the MCS51 microprocessor bus.

Although microprocessors are ideal for use in control circuits, they are not easy to communicate with. An LC display may help. Since most of such displays use an Hitachi controller, it is fairly easy to design a standard interface conform with the specification of the controller.

Figure 1 shows a display module integrated in a microprocessor bus as found in any MCS51 system. Many signals, such as those on the data bus and address line, and the supply voltage can be applied directly. Since the module puts a number of demands on the the timing of the $R/\overline{W}$ signal and the E input, control of the $R/\overline{W}$ line and the E input requires a small modification.

The signals of most importance for the LC module are shown in **Fig. 2**. It will be seen that signals RS and $R/\overline{W}$ must be active at least 140 ns before the E signal and that the E signal itself must be at least 450 ns long. Finally, during a write operation, RS, $R/\overline{W}$ and the signal on the data bus must remain active for not less than 20 ns after the E line has been deactuated.

As far as the microcontroller is concerned, data are usually taken from the databus at the edge of the $R/\overline{W}$ signal. This edge occurs within the time that the valid address as well as the correct data are available on the buses. The location of the enable signal (E) needed by the LC module can not be found in the signal diagram.

All timing signals of the processor have been derived directly from the system clock and are, therefore, multiples of the periods of the clock frequency used by the controller. It is, however, necessary in a number of cases to reduce these times by some nanoseconds in order to eliminate the delays in the various sub-circuits of the processor. **Figure 3** shows the timing of the signals on the MCS51 bus.

As shown in **Fig. 1**, the LC display is controlled by signals $\overline{LCD}$, $\overline{RD}$, $\overline{WR}$ and A0. The only way of meeting the timing requirements of the display is by including address line A0 in the read/write signal for the LC module. This address line is made valid well before the $R/\overline{W}$ edge appears on the processor bus. The consequence of this is that a different address must be chosen every time the module is read from or written to. During writing, the level at the $R/\overline{W}$ input must be low: A0 is then also low. During reading, the level of $R/\overline{W}$ must be high; A0 is then high also. Signal $\overline{LCD}$> derives from the address decoder and this selects the display at auser-chosen address. Here, the basic address of the LCD module is $D000_H$, so that the complete address is as follows:

Write command	Write	$D000_H$
Read command	Read	$D001_H$
Write data	Write	$D002_H$
Read data	Read	$D003_H$.

Next, the length of the various signals as a function of the processor clock can be determined. Remember the earlier stated limits.

clock (MHz)	t_{as} (ns)	PW_{EH} (ns)	t_H (ns)
8	325	650	75
10	250	500	50
12	200	400	33.3
16	138	275	12.5

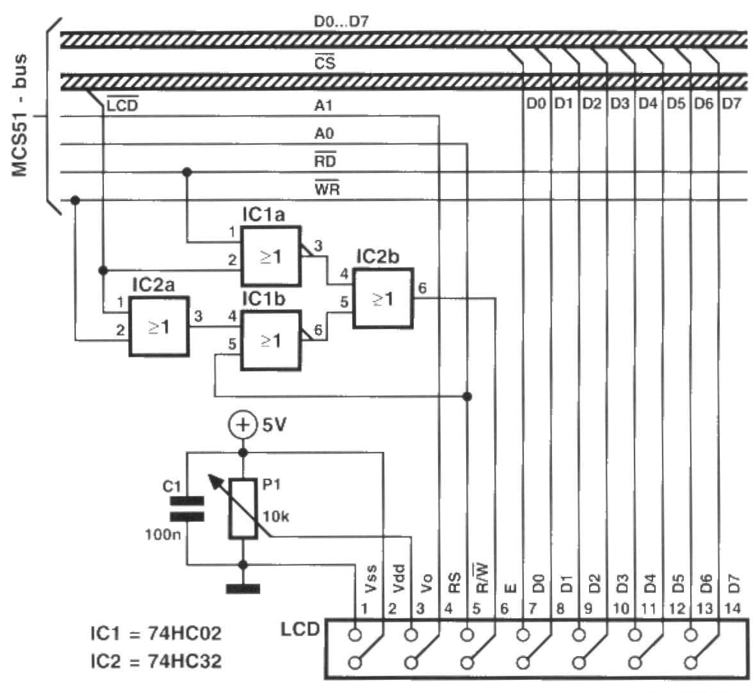


Fig. 1. Integrating an LCD module into an MCS51 system

Up to a clock frequency of 10.9 MHz, everything works out all right, but at higher ones matters go awry. For such higher clock frequencies, the only solution is to connect the display to an I/O port. Depending on the chosen mode (4 or 8 bits), seven or 11 data lines are then required.

Finally, the control voltage required for setting the contrast is applied to the display via P_1. In most cases, a control range of 0–5 V will be found more than adequate.

END

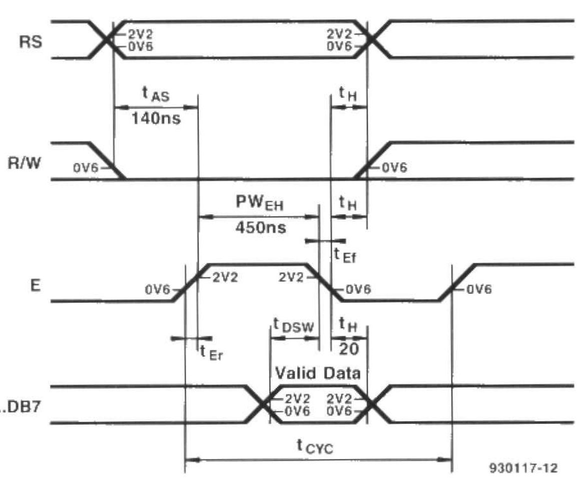


Fig. 2. The LCVD module puts certain demands on the timing.

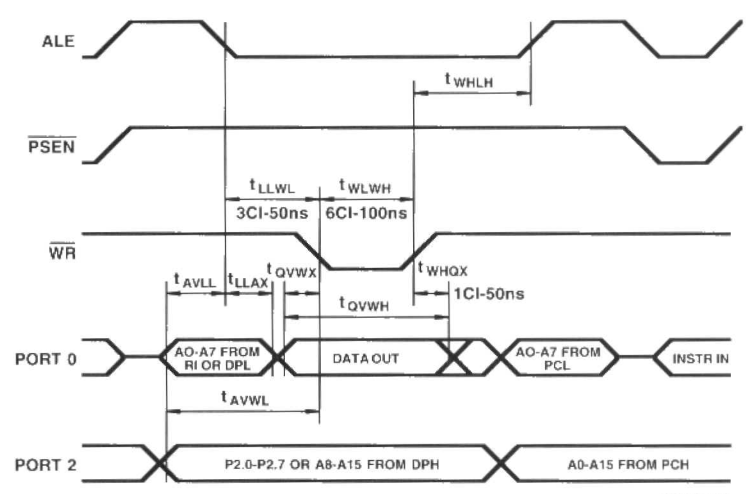


Fig. 3. Timing diagram of the MCS51 bus.

BUILDING YOUR OWN TOROID CORE INDUCTORS AND RF TRANSFORMERS

By Joseph J. Carr

A lot of electronic construction projects intended for hobbyists and amateur radio operators call for inductors or radio frequency (RF) transformers wound on toroidal cores. A **toroid** is a doughnut shaped object, i.e. a short, flat cylinder (often with rounded edges) that has a hole in the centre (see **Fig. 1**). The toroidal shape is desirable for inductors

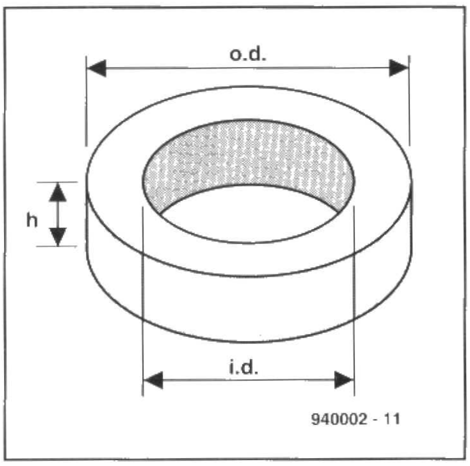


Fig. 1. The toroid coil form.

because it permits a relatively high inductance value with few turns of wire by virtue of the core's **permeability** (μ), and, perhaps most important, the geometry of the core makes the coil self-shielding. That latter attribute makes the toroid inductor easier to use in practical RF circuits. Regular solenoid-wound cylindrical inductors have a magnetic field that goes outside the immediate vicinity of the windings, and can thus intersect nearby inductors and other objects. Unintentional inductive coupling can cause a lot of serious problems in RF electronic circuits, so should be avoided wherever possible. The use of a toroidal shape factor, with its limited external magnetic field, makes it possible to mount the inductor close to other inductors (and other components) without too much undesired interaction.

Materials used In toroidal cores

Toroidal cores come in a variety of materials that are usually grouped into two general classes: **powdered iron** and **ferrites**. These groups are further subdivided as discussed below.

Powdered iron materials.
The powdered iron cores come in two basic formulations: **Carbonyl Irons** and **Hydrogen Reduced Irons**. The Carbonyl materials are well regarded for their temperature stability; they have relative permeability (μ_r) values that range from 1 to about 35. The Carbonyls offer very good 'Q' values to frequencies of 200 MHz. Carbonyls are used in high power applications, as well as in variable frequency oscillators and wherever temperature stability becomes important. However, note that no powdered iron material or ferrite is totally free of temperature variation, so oscillators using these cores must be temperature compensated for proper operation. The Hydrogen Reduced iron devices offer relative permeabilities up to 90, but are lower 'Q' than Carbonyl devices. They find their main usage in electromagnetic interference (EMI) filters. The powdered iron materials are the subject of **Table 1**.

Ferrite materials.
The name 'ferrite' implies that the material is iron-based, but that is not the case; ferrite materials are actually grouped into **nickel-zinc** and **manganese-zinc** types. The nickel-zinc material has a high volume resistivity and high Q over the range 0.50 to 100 MHz. The temperature stability is only moderate, however. The relative permeabilities of nickel-zinc materials are found in the range 125 to 850. The manganese-zinc materials have higher relative permeabilities than nickel-zinc, and are of the order of 850 to 5,000. Manganese-zinc materials offer high Q over the range 1 kHz to 1 MHz. They have low volume resistivity and moderate saturation flux density. These materials are used in switching power supplies from 20 to 100 KHz, and for EMI attenuation in the range 20 to 400 MHz. See **Table 2** for additional information on ferrite materials.

Toroid core nomenclature

Although there are several different ways to designate toroidal cores, the one used by **Amidon Associates** [2216 East Gladwick, Dominguez Hills, CA, 90220, USA; 310-763-5770 (voice) or 310-763-2250 (fax)] is perhaps that most commonly found in electronic hobbyist and

Material	μ_r	Comments
0	1	Used up to 200 MHz. Inductance varies with method of winding.
1	20	Made of Carbonyl C. Similar to Mixture No. 3 but is more stable, and has a higher volume resistivity.
2	10	Made of Carbonyl E. High Q and good volume resistivity over range of 1 to 30 MHz
3	35	Made of Carbonyl HP. Very good stability and good Q over range of 50 kHz to 500 kHz.
6	8	Made of Carbonyl SF. Is similar to mixture no. 2, but has higher Q over range 20 to 50 MHz.
10	6	Type W powdered iron. Good Q and high stability from 40 to 100 MHz.
12	3	Made of a synthetic oxide material. Good Q but only moderate stability over the range 50 to 100 MHz.
15	25	Made of Carbonyl GS6. Excellent stability and good Q over range 0.1 to 2 MHz. Recommended for AM BCB and VLF applications.
17	3	Carbonyl material similar to mixture no. 12, but has greater temperature stability but lower Q than no. 12.
26	75	Made of Hydrogen Reduced Iron. Has very high permeability. Used in EMI filters and DC chokes.

Table 1. Powdered iron core materials.

amateur radio published projects. Although the units of measure are the English system used in the USA, Canada and formerly in UK, rather than SI units, their use with respect to toroids seems widespread. The type number for any given core will consist of three elements: **xx-yy-zz**. The 'xx' is a one or two letter designation of the general class of material, i.e. powdered iron (xx = 'T') or ferrite (xx = 'TF'). The 'yy' is an rounded off approximation of the outside diameter ('o.d.' in **Fig. 1**) of the core in inches; '37' indicates a 0.375-inch (9.53-mm) core, while '50' indicates a 0.50-inch (12.7-mm). The 'zz' indicates the type (mixture) of material. A mixture no. 2 powdered iron core of 0.50 inch diameter would be listed as a T-50-2 core. The cores are colour coded to assist in identification.

Inductance of toroidal coils

The inductance, L, of the toroidal core inductor is a function of the relative permeability of the core material, the number of turns, the inside diameter (i.d.) of the core, the outside diameter (o.d.) of the core, and the height (h) — see **Fig. 1**, and can be approximated by:

$$L = 0.011684\, h\, N^2\, \mu_r \log_{10}\left(\frac{\text{o.d.}}{\text{i.d.}}\right) \quad \text{(H)} \qquad [1]$$

This equation is rarely used directly, however, because toroid manufacturers provide a parameter called the $\mathbf{A_L}$ value which relates inductance per 100 or 1,000 turns of wire. Tables 3 and 4 show the A_L values of common ferrite and powdered iron cores, respectively. Table 5 shows some of the other properties of powdered iron cores.

Winding toroid inductors

There are two basic ways to wind a toroidal core inductor: **close spaced winding** and **distributed winding**. In distributed winding toroidal inductors the turns of wire that are wound on the toroidal core are spaced evenly around the circumference of the core, with the exception of a gap of at least 30° between the ends (see **Fig. 2a**). The gap ensures that stray capacitance is kept to a minimum. The winding covers only 270° of the core circumference. In close winding toroids (Fig. 2b) the turns are made such that adjacent turns of wire touch each other, or nearly so. This practice raises the stray capacitance of the winding, which affects the resonant frequency, but can be done in many cases with little or no ill effect (especially where the capacitance and resonant point shift are negligible). In general, close winding is used for inductors in narrow band tuned circuits, while distributed winding is used for broadband situations like conventional and BALUN RF transformers. The method of winding has a small effect on the final inductance of the coil. While this fact makes calculating the final inductance less predictable, it also provides a means of final adjustment of actual inductance in the circuit as-built.

N-Z: Nickel-Zinc
M-Z: Manganese-Zinc

Material	μ_r	Remarks
33	850	M-Z. Used over 1 kHz to 1 MHz for loopstick antenna rods. Low volume resistivity.
43	850	N-Z. Medium wave inductors and wideband transformers to 50 MHz. High attenuation over 30 to 400 MHz. High volume resistivity.
61	125	N-Z. High Q over 0.2 to 15 MHz. Moderate temperature stability. Used for wideband transformers to 200 MHz.
63	40	High Q over 15 to 25 MHz. Low permeability and high volume resistivity.
67	40	N-Z. High Q operation over 10 to 80 MHz. Relatively high flux density and good temperature stability. Is similar to Type 63, but has lower volume resistivity. Used in wideband transformers to 200 MHz.
68	20	N-Z. Excellent temperature stability and high Q over 80 to 180 MHz. High volume resistivity.
72	2000	High Q to 0.50 MHz, but used in EMI filters from 0.50 to 50 MHz. Low volume resistivity.
J/75	5000	Used in pulse and wideband transformers from 1 kHz to 1 MHz, and in EMI filters from 0.50 to 20 MHz. Low volume resistivity and low core losses.
77	2000	0.001 to 1 MHz. Used in wideband transformers and power converters, and in EMI and noise filters from 0.5 to 50 MHz.
F	3000	Is similar to Type 77 above, but offers a higher volume resistivity, higher initial permeability, and higher flux saturation density. Used for power converters and in EMI/noisefilters from 0.50 to 50 MHz.

Table 2. Ferrite materials.

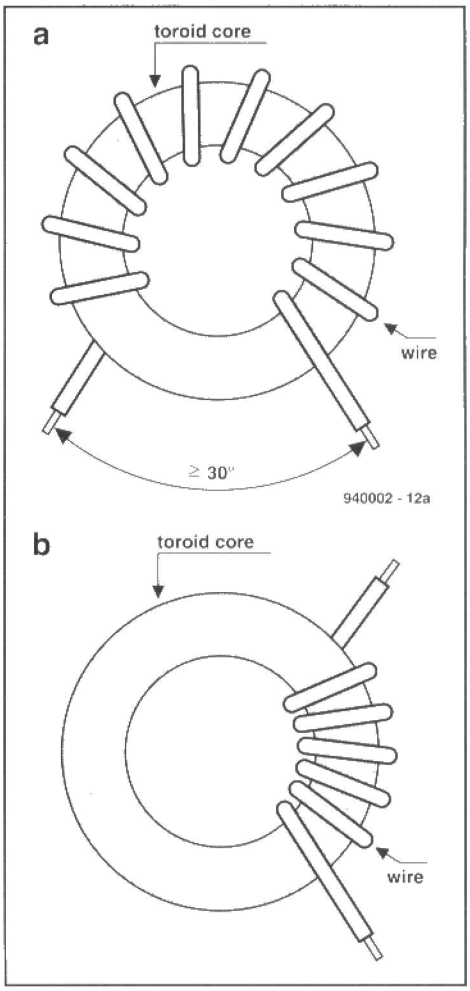


Fig. 2. Toroid winding styles: a) distributed; b) close wound.

Calculating the number of turns needed

As in all inductors, the number of turns of wire determines the inductance of the finished coil. In powdered iron cores the A_L rating of the core is used with fair confidence to predict the number of turns needed.

For powdered iron cores:

$$N = 100\sqrt{(L / A_L)} \qquad [2]$$

Where:
N is the number of turns;
L is the inductance required in microhenrys (µH);
A_L is an attribute of the core material and size (µH/100 turns).

Example
Find the number of turns of wire required to make a 6-µH inductance from a

T-50-2 (red) powdered iron core (A_L=49).

$$N = 100\sqrt{(6\mu H/49)} = 35 \text{ turns.}$$

For ferrite cores:

$$N = 1000\sqrt{(L/A_L)} \qquad [3]$$

Where:
L is the inductance required in millihenrys (mH)
A_L is an attribute of the core material and size (mH/1000 turns)

Example
How many turns are needed to wind a 200-μH inductor on a ferrite FT-50A-43 core (A_L = 570 mH/1000 turns)? Note: 200 μH = 0.2 mH.

$$N = 1000\sqrt{(0.2/570)} = 18.7 \text{ turns}$$

The number of turns calculation often comes out to a fraction of a turn. With the possible exception of 0.5 turns, the actual turns count should be rounded off to the nearest turn. It is possible to round off to the nearest half turn, but it is not as easy to implement in practice.

Building the toroidal device

The toroid core or transformer is usually wound with enamelled or formvar insulated wire. For low powered applications (receivers, variable frequency oscillators, etc.) the wire will usually be SWG22 through SWG36 (with SWG26 being very common). For high power applications, such as transmitters and RF power amplifiers, a heavier grade of wire is needed. For amateur high power applications, SWG14 or SWG12 wire is usually specified, although wire as large as SWG6 has been used in some commercial applications. Again, the wire is enamelled or formvar covered insulated wire. In the high power case it is likely that high voltages will exist. In high powered RF amplifiers, such as used by amateur radio operators in many countries, the potentials present across a 50-Ω circuit can reach hundreds of volts. In those cases, it is common practice to wrap the core with a glass-based tape such as **Scotch 27**.

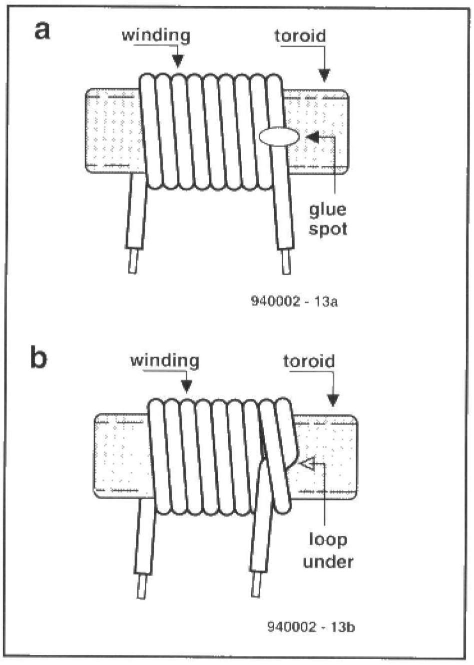


Fig. 3. Methods for fastening the wire on a toroid winding: a) glue spot; b) 'tuck under' method.

High powered applications also require a large area toroid, rather than the small toroids that are practical at lower power levels. Cores in the FT-150-zz to FT-240-zz, or T-130-zz to T-500-zz are typically used. In some high powered cases several identical toroids are stacked together, and wrapped with tape to increase the power handling capacity. This method is used quite commonly in RF power amplifier and antenna tuning unit projects.

Binding the wires

It sometimes happens that the wires making up the toroidal inductor or transformer become loose. Some builders prefer to fasten the wire to the core using one of the two methods shown in **Fig. 3**. In **Fig. 3a** we see the use of a dab of glue, silicone adhesive, or the high voltage sealant **Glyptol** (sometimes used in television receiver high voltage circuits) to anchor the end of the wire to the toroid core.

Other builders prefer the method shown in **Fig. 3b**. In this method, the end of the wire is looped underneath the first full turn and pulled taut. This method will effectively anchor the wire, but some say it creates an anomaly in the magnetic situation that may provoke interactions with nearby components. In my experience, that situation is not terribly likely, and I use the method regularly with no observed problems thus far.

When the final coil is ready, and both the turns count and spacing are adjusted to yield the required inductance, the turns can be anchored and the coil placed in service. A final sealing method is to coat the coil with a thin layer of clear lacquer, or 'Q-dope' (which product is intended by its manufacturer as an inductor sealant).

Mounting the toroidal core device

Toroids are sometimes a bit more difficult to mount than solenoid wound coils, but the rules that one must follow are not as strict. The reason for loosening of the mounting rules is that the toroid, when built correctly, is essentially self-shielding so less attention (not NO attention!) may be paid to components surrounding the inductor. In the solenoid wound coil, for example, the distance between adjacent coils and their orientation is important. Adjacent coils, unless well shielded, must be placed at right angles to each other to lessen the mutual coupling between the coils. However, toroidal inductors can be closer together and either co-planar or adjacent planar with respect to each other. While some spacing must be maintained between toroidal cores (the winding and core manufacture not being perfect), the required average distance can be less than for solenoid wound cores.

Mechanical stability of the mounting is always a consideration for any coil (indeed, any electronic component). For most benign environments, the core can be mounted directed to a printed circuit board (PCB) in the manner of **Figs. 4a** and **4b**. In **Fig. 4a**, the toroidal inductor is mounted flat against the board; its leads are passed through holes in the board to solder pads underneath. The method of **Fig. 4b** places the toroid at right angles to the board, but still uses the leads soldered to copper pads on the PCB to anchor the coil. It is wise to use a small amount of RTV silicone sealant or glue to hold the coil to the board once it is found to work satisfactorily.

If the environment is less benign with respect to vibration levels, a method similar to **Fig. 4c** may be employed. Here the toroid is fastened to the PCB with a

Core type no. prefix: FT-yy-zz

Core size	Material type 43	61	63	72	75	77
23	188	24.8	7.9	396	990	356
37	420	55.3	17.7	884	2210	796
50	523	68	22	1100	2750	990
50A	570	75	24	1200	2990	1080
50B	1140	150	48	2400	—	2160
82	557	73.3	22.8	1170	3020	1060
114	603	79.3	25.4	1270	3170	1140
114A	—	146	—	2340	—	—
240	1249	173	53	3130	6845	3130

Table 3. Common ferrite core A_L values.

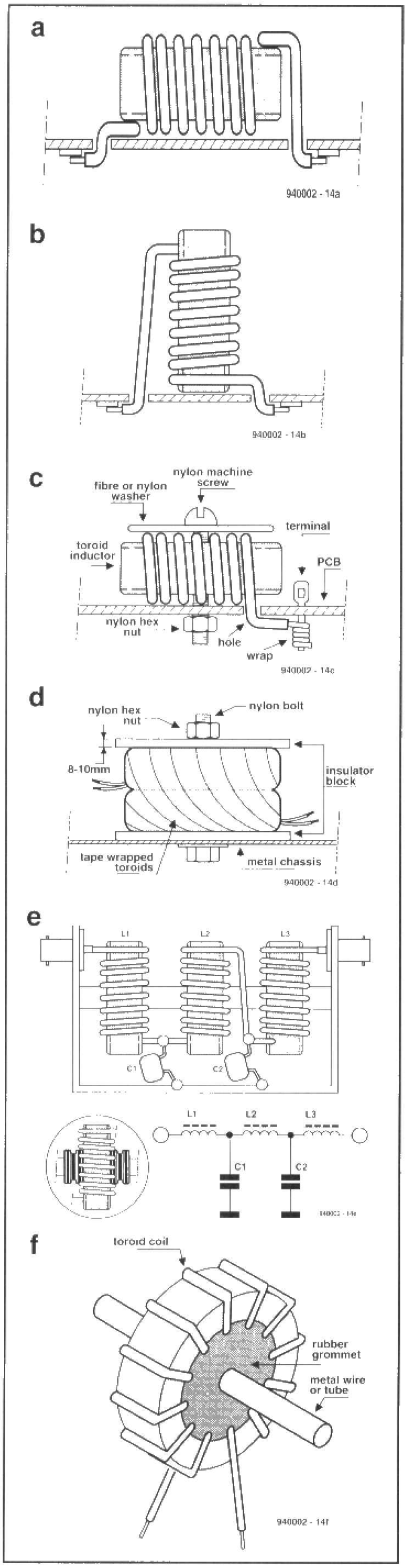


Fig. 4. a) flat mounting; b) on-end mounting; c) secured mounting (use nylon machine screws); d) mounting high power or high voltage toroidal inductors or transformers; e) suspending toroid inductors on a dowel; f) mounting method for a 'single turn primary' transformer in RF watt-meters or VSWR meters.

set of nylon machine screw and nut hardware, and a nylon or fibre washer. In high powered antenna tuning units it is common to see an arrangement similar to **Fig. 4d**. In this configuration, several toroidal cores are individually wrapped in glass tape, and then the entire assembly is wrapped as a unit with the same tape. This assembly is mounted between two insulators such as plastics, ceramic, or fibreboard, which are held together as a 'sandwich' by a nylon bolt and hex nut.

Figure 4e shows a method for suspending toroidal cores in a shielded enclosure. I have used this method to make five-element low pass filters (see inset) for use on my basement laboratory workbench. The toroidal inductors are mounted on a dowel which is made of some insulating material such as wood, plastic, plexiglass, Lexan or other synthetic material. If the dowel is sized correctly, the inductors will be a tight slip fit, and need no further anchoring. Otherwise, a small amount of glue or RTV silicone sealant can serve to stabilize the position of the inductor. Care must be observed against force fitting, however, in order to avoid fracturing the toroid core.

Some people use a pair of undersized rubber grommets over the dowel, one pressed against either side of the inductor (see inset to **Fig. 4e**). If the grommets are taut enough, no further action is needed. Otherwise, they can be glued to the rod.

A related mounting method is used to make current transformers in home made RF power meters (**Fig. 4f**). In this case a rubber grommet is fitted into the centre of the toroid, and a small brass or copper rod is passed through the centre hole of the grommet. The metal rod serves as a one-turn primary winding. A sample of the RF current flowing in the metal rod is magnetically coupled to the secondary winding on the toroid, where it can be either fed to an oscilloscope for display, or rectified, filtered and displayed on a d.c. current meter that is calibrated in watts or VSWR units.

Toroidal RF transformers

Both narrow band tuned and broadband RF transformers can be accommodated by toroidal powdered iron and ferrite cores. The schematic symbols used for transformers are shown in **Fig. 5**. These symbols are largely interchangeable, and are all seen from time to time. In **Fig. 5a** the two winding are shown adjacent to each other, but the core is shown along only one of them. This method is used to keep the drawing simple and does not imply in any way that the core does not affect one of the windings. The core may be represented either by one or more straight lines, as shown, or by dotted lines. The method shown in **Fig. 5b** is like the conventional transformer representation in which the windings are juxtaposed opposite each other with the core between them. In **Fig. 5c** the core is extended and the two windings are along one side of the core bars.

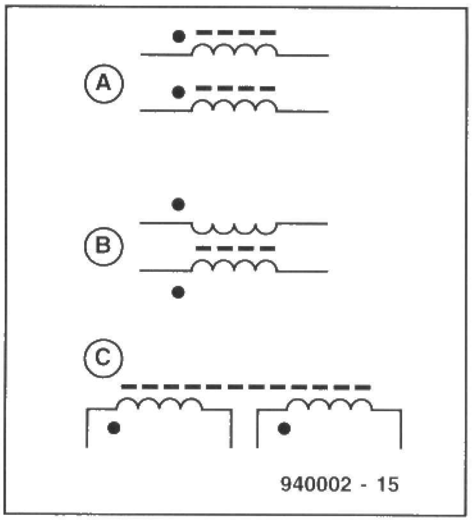


Fig. 5. Transformer symbols.

In each of the transformer representations of **Fig. 5** there are dots shown on the windings. These dots tell us the 'sense' of the winding, and represent the same end of the coils. Thus, the wires from two dotted ends are brought to the same location, and the two coils are wound in the same direction. Another way of looking at it is that if a third winding were used to excite the core from an RF source, the phase of the signals at the dot ends will be the same; the phase of the signal at the undotted ends will also be the same, but will be opposite that of the dotted ends.

The windings of the toroidal transformer can be spaced at different locations around the circumference of the toroid when the device is narrow band, but for wideband operation a **bifilar winding** scheme is used (**Fig. 6**). In this type of winding scheme, the wires, A and B, are held closely parallel to each other as they are wound around the core. When the job is finished, ends A1 and B1 will be at the same location, while A2 and B2 will be at another location on the toroid core.

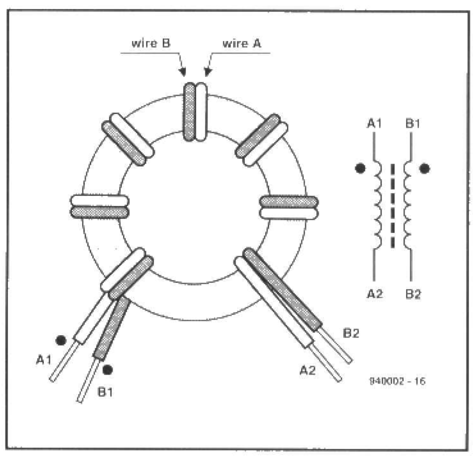


Fig. 6. Bifilar winding style.

Conventional transformers

Core size	26	3	15	1	2	6	10	12	0
	Core material type (mix)								
12	—	60	50	48	20	17	12	7	3
16	—	61	55	44	22	19	13	8	3
20	—	90	65	52	27	22	16	10	3.5
37	275	120	90	80	40	30	25	15	4.9
50	320	175	135	100	49	40	31	18	6.4
68	420	195	180	115	57	47	32	21	7.5
94	590	248	200	160	84	70	58	32	10.6
130	785	350	250	200	110	96	—	—	15
200	895	425	—	250	120	100	—	—	—

Table 4. Common powdered iron A_L values.

One of the principal uses of transformers in RF circuits is impedance transformation. When the secondary winding of a transformer is connected to a load impedance, the impedance seen 'looking into' the primary will be a function of the load impedance and the turns ratio of the transformer (see **Fig. 6a**). The relationship is:

$$(N_p / N_s) = \sqrt{(Z_p / Z_s)} \qquad [4]$$

With the relationship of Eq. [4] we can match source and load impedances in RF circuits.

Example
Assume that we have a 3 to 30 MHz transistor RF amplifier with a base input impedance of 4 Ω (Z_s), and that transistor amplifier has to be matched to a 50-Ω source impedance (Z_p), as shown in **Fig. 7b**. What turns ratio is needed to effect the impedance match? Let's calculate:

$$N_p / N_s = \sqrt{(50/3)} = 3.53{:}1.$$

A general design rule for the value of inductance used in transformers is that the inductive reactance at the lowest frequency must be four times the impedance connected to that winding. In the case of the 50-Ω primary of the transformer above, then, the inductive reactance of the primary winding should be 4×50 Ω, or 200 Ω. The inductance should be:

$$L = \frac{200\Omega\ 10^6}{2\pi F}$$

$$L = \frac{200\Omega\ 10^6}{2\pi 3{,}000{,}000} = 10.6\ \mu\text{H}$$

Now that we know that a 10.6-μH inductance is needed, we can select a toroidal core and calculate the number of turns needed. The T-50-2 (red) core covers the correct frequency range, and is of a size that is congenial to easy construction. The T-50-2 (red) core has an A_L value of 49, so the number of turns required:

$$N = 100\ \sqrt{(10.6\ \mu\text{H} / 49)} = 47 \text{ turns}.$$

The number of turns in the secondary must be such that the 3.53:1 ratio is preserved when 47 turns are used in the primary:

$$N_s = 47 / 3.53 = 13.3 \text{ turns}.$$

If we wind the primary with 47 turns, and the secondary with 13 turns, then we will convert the 4-Ω transistor base impedance to the 50-Ω system's impedance.

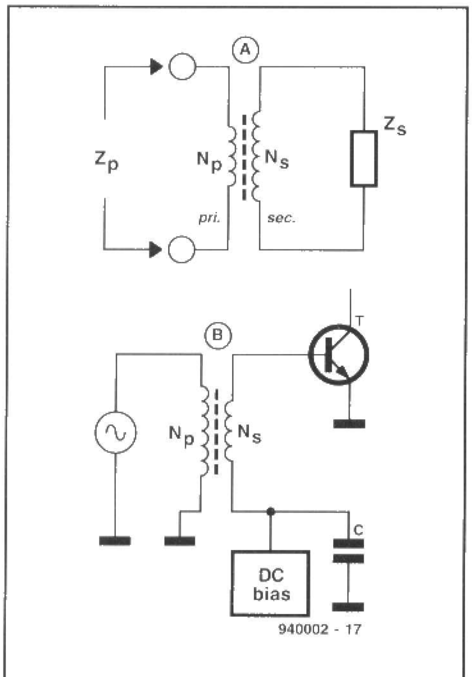


Fig. 7. a) generic transformer and load. Impedance seen looking into the primary is a function of the secondary impedance and the transformer turns ratio; b) Step-down impedance transformer coupling a 50 ohm input to an RF transistor.

Example
A Beverage Wave antenna is constructed for the AM broadcast band (530-1700 KHz). By virtue of its construction and installation, it exhibits a characteristic impedance Z_o of 600 Ω. What is the turns ratio required of a transformer at the feed end (**Fig. 8**) to match a 50-Ω receiver input impedance?

$$(N_s / N_p) = \sqrt{(600\Omega / 50\Omega)} = 3.46{:}1$$

The secondary requires an inductive reactance of 4×600 Ω, or 2,400 Ω. To obtain this inductive reactance at the lowest frequency of operation requires an inductance of:

$$L = \frac{2{,}400\Omega\ 10^6}{2\pi 530{,}000} = 721\ \mu\text{H}$$

Checking a table of powdered iron toroid cores, it is found that the -15 (red/wht) mixture will operate over the 0.1 to 2 MHz region. Selecting a T-106-15 (red/wht) core gives us an A_L value of 345. The number of turns required to create an inductance of 721 μH is:

$$L = 100\ \sqrt{(721 / 345)} = 145 \text{ turns}$$

The primary winding must have:

$$N_p = 145 / 3.46 = 42 \text{ turns}.$$

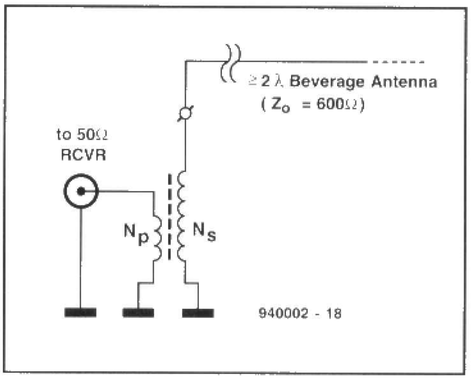


Fig. 8. Transformer coupling of 600-ohm Beverage antenna to a 50-ohm receiver input.

Winding the conventional transformer

When the windings of the conventional transformer are equal, i.e., where the turns ratio is 1:1, it is universal practice to wind the two coils in the bifilar manner discussed above (see **Fig. 6**). A special case of RF transformers called BALUN transformers (discussed below) uses this manner of winding exclusively. In cases where the windings are not equal, as is often the case in conventional transformers, there are three approaches to winding the coils. **Figure 9a** shows an RF transformer in which high impedance (high-Z) and low impedance (low-Z) windings are used. The two different styles of winding the coils are shown in **Figs. 9b** and **9c**. The method shown in **Fig. 9b** keeps the primary and secondary separated on the core. This method is suitable for use in narrow bandwidth applications, for example in the tuning circuit of a radio receiver. The method in **Fig. 9c** intersperses the turns of the low-

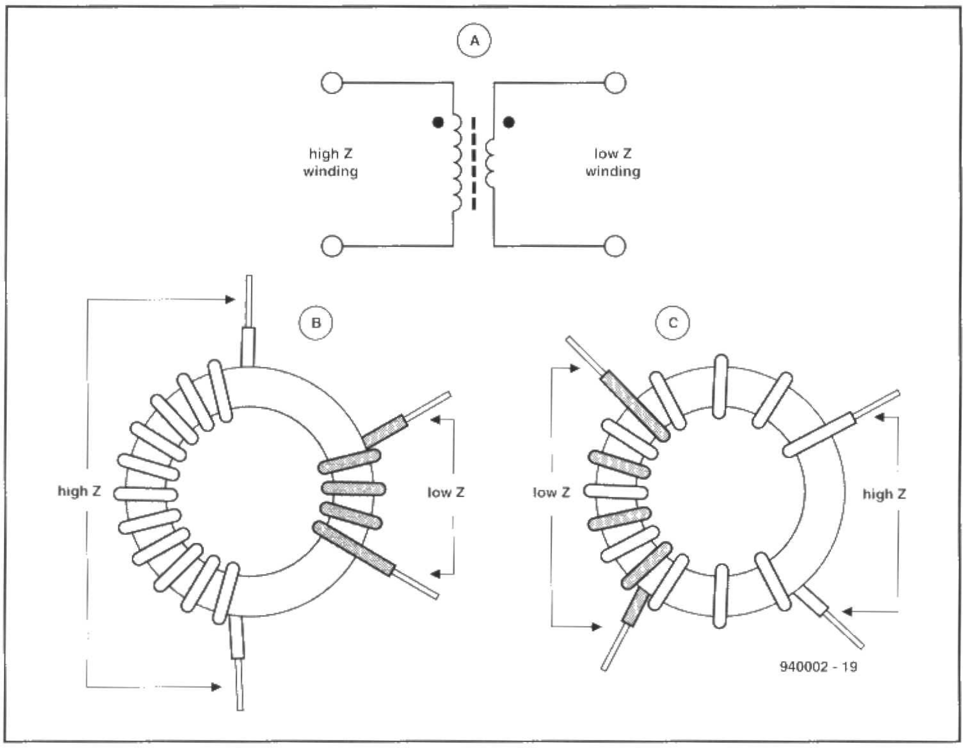


Fig. 9. a) two-winding RF transformer; b) separated windings; c) interleaved or bifilar winding.

Z winding over or among the windings of the high-Z winding. This method can be used for narrow band or relatively wide-band applications. But if the transformer must be truly wideband, the best winding method is to wind the low-Z and high-Z coils in the bifilar manner as far as is needed to accommodate the low-Z winding. Starting from one point on the core, the wires are kept bifilar until the low-Z coil is completed, and then monofilar the rest of the way until the high-Z part is completed.

Connecting the conventional transformer in the circuit

A conventional RF transformer schematic symbol may have small dots, or some other device, to indicate the sense of the windings. They can also be used to determine the phasing of the signal transmitted through the transformer. In **Fig. 10a** the same ends of both windings are grounded, so the output signal is in phase with the input signal. In **Fig. 10b**, on the other hand, the opposite ends of the two windings are grounded, so the output signal is 180 degrees out of phase with the input signal.

Autotransformers

An **autotransformer** differs from conventional transformers in that there is only one winding, which is tapped to provide the two impedance levels needed. **Figure 11** shows the autotransformer in two different connection schemes. The connection scheme in **Fig. 11a** results in an in-phase output signal, while that of **Fig. 11b** produces an out of phase signal across the load.

Winding the autotransformer proceeds along the same lines as for a straight coil, except that the two sections of the winding are broken at a point to create the tap. There are two schemes used in doing this job. In one method, the entire winding is one continuous piece of wire. A small loop is made at the tap, and made available to the rest of the circuit. The enameled insulation can be scrapped away and the wire tinned with solder. The other method, as shown in **Fig. 12**, breaks the two sections into two discrete windings, A-B and B-C. The connection at the junction is soldered for electrical and mechanical integrity. It is very important that the two windings maintain the same sense. The A-B winding and B-C windings must be wound in the same direction. The starting turns of both sections in **Fig. 12** start in the same direction, as is needed to maintain the sense of the coils.

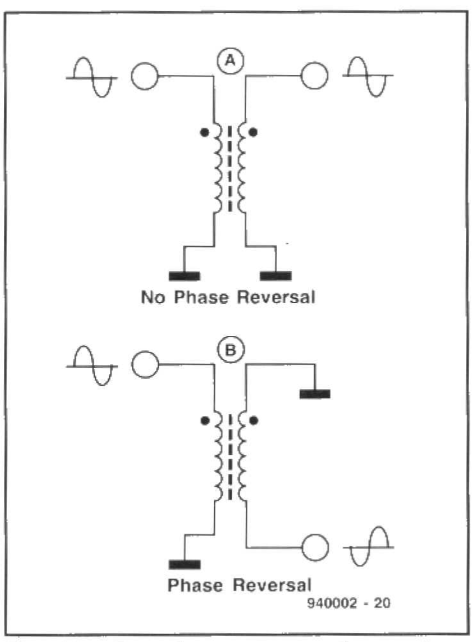


Fig. 10. Transformer connections: a) no phase reversal; b) phase reversal.

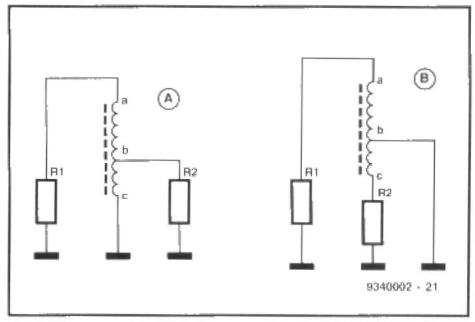


Fig. 11. Autotransformer connections: a) no phase reversal; b) phase reversal.

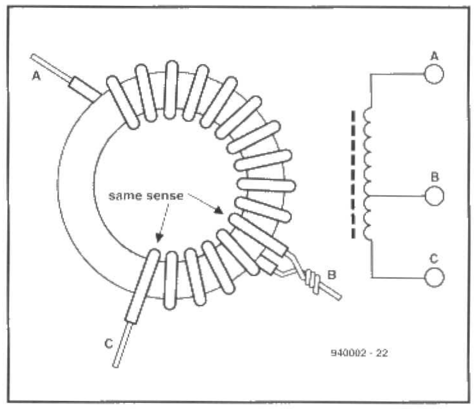


Fig. 12. Wiring detail for the auto-transformer.

BALUNs, BAL-BALs and UN-UNs

There is a special category of RF transformer that are sometimes called **transmission line transformers**. These devices are available in several different configurations depending on the type of load at each winding and the impedance ratio. The **balun** transformer gets its name from **BALanced-UNbalanced**, which describes the relationship between the source and load types. In the balun, one load will be unbalanced with respect to ground (e.g. a coaxial cable from a standard 50-Ω transmitter output), while the other will be balanced with respect to ground (e.g. a dipole antenna). Amateur radio operators and SWLs often use 1:1 impedance ratio balun transformers at the feedpoint of dipole and other balanced antennas because it ensures that the pattern is a more nearly ideal bidirectional 'figure-8'. Other common balun devices are available in 4:1 impedance ratios. These devices can be used to match the feedpoint impedances of high impedance antennas such as the G5RV, the folded dipole, or the long wire.

Figure 13 shows the two most common forms of voltage balun transformer. In the 1:1 impedance ratio version shown in **Fig. 13a** there are three bifilar windings on the same core, while in the 4:1 impedance ratio version of **Fig. 13b** there are two bifilar windings. In both cases, the sense of the windings are very important, and must be scrupulously observed.

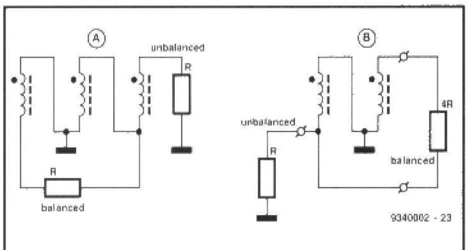


Fig. 13. a) 1:1 BALUN transformer; b) 4:1 BALUN transformer.

Material type	Colour code	μ_r	Frequency (MHz)
41	green	75	—
3	grey	35	0.05 - 0.5
15	red/white	25	0.1 - 2
1	blue	20	0.5 - 5
2	red	10	1 - 30
6	yellow	8	10 - 90
10	black	6	60 - 150
12	green/white	3	100 - 200
0	tan	1	150 - 300

Table 5. Properties of powdered iron core types.

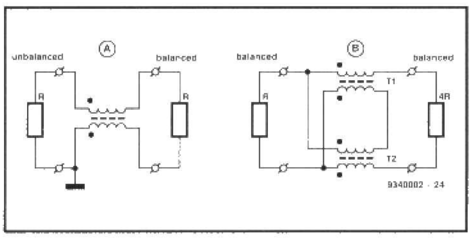


Fig. 14. a) RF isolation 'pseudo-BALUN' transformer; b) 4:1 current BAL-BAL transformer.

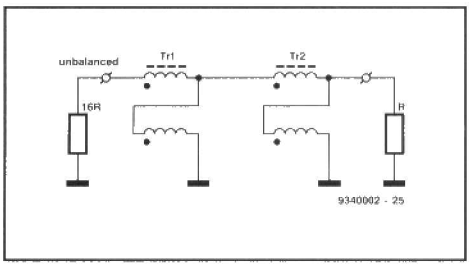


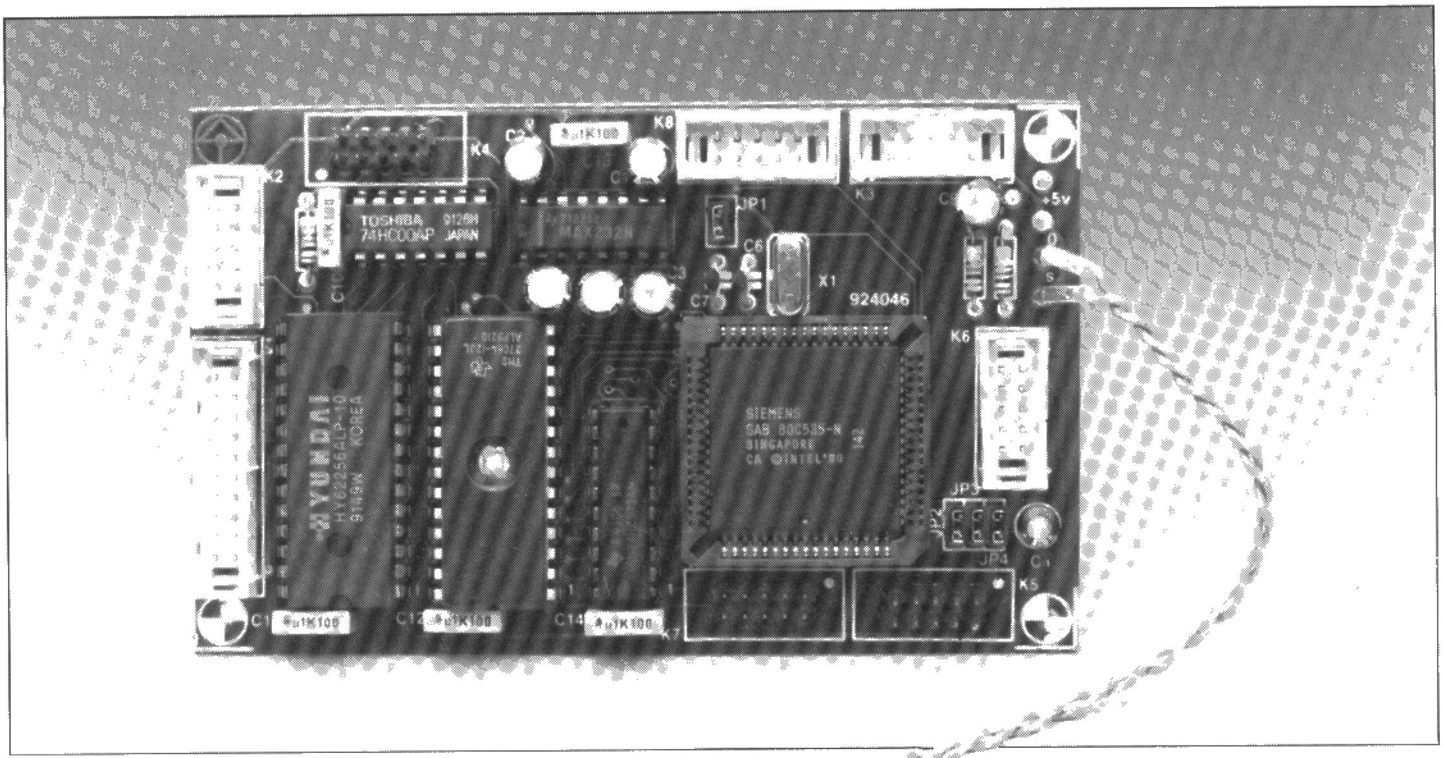
Fig. 15. 16:1 UN-UN RF transformer.

A pair of RF transformers are shown in **Fig. 14**. Although the transformer of **Fig. 14a** is usually called a 1:1 balun transformer in the literature, it is not technically in that category. Instead, it is an RF isolation transformer. It does serve the function of converting the balanced load to an unbalanced form that is compatible with the unbalanced input.

The transformer shown in **Fig. 14b** is a bal-bal in that it has a balanced load at both ends. The impedance ratio of this transformer is 4:1. It can be used to convert high impedance antenna feedpoints to a lower impedance while retaining the balanced feature. It is also occasionally used in RF power amplifier circuits. This circuit actually consists of two transformers connected together.

The circuit shown in **Fig. 15** is an un-un transformer, i.e., it has an unbalanced load at both ends. This device is actually a pair of 4:1 transformers in cascade, resulting in a 16:1 impedance ratio. One use for this transformer is to convert extremely low impedances to 50 Ω, as might be seen in RF power amplifiers or in vertical antennas in some installation situations. An example might be the 3 to 4-Ω base impedance in a bipolar transistor RF power amplifier circuit. In order to match the 50-Ω input impedance of the system, the 16:1 un-un transformer of **Fig. 15** can be used. ■

80C535 SINGLE-BOARD COMPUTER



Versatile and easy to build, the single-board computer described here is packed with goodies for the many microcontroller enthusiasts among you: ROM, RAM, a powerful 80C535 CPU, I/O ports, an ADC and an RS232 interface, all on an extremely compact board. The hardware is complemented by a monitor program in EPROM which allows you to use your PC to communicate with the 80C535. What's more, a short 80C535 programming course will be started next month.

Design by Dr. M. Ohsmann

As you can see from the above photograph, the printed circuit board designed for the 80C535 computer has been layed out with 'connectivity' in mind. All essential connections of the microcontroller are accessible via box-headers fitted at the edges of the board. The computer is 'ready to go' with the EMON51 monitor EPROM (Ref. 1) fitted in the ROM socket, and is fully compatible with all 8051/80C32 programs. The 80C535 computer has an on-board 'RxD/TxD only' RS232 interface, which is easily connected to a PC running a communication program, or the V24 program downloader found on the 8051/8032 assembler course diskette. The RS232 interface on the present board has its own symmetrical voltage converter.

Apart from 32 KBytes of ROM and RAM, the board contains eight analogue signal inputs with a resolution of up to 10 bits. The ADC which reads the analogue signal levels is contained in the SAB80C535 microcontroller. The SAB80C535 from Siemens is an upgrade of the Intel 8051, to which it is fully software compatible. Consequently, those of you who have already done some 8051 programming can 'upgrade' to the 80C535 without problems. Note, however, that the 80C535 has quite a few extra features with regard to the 8051. These fea-

MAIN SPECIFICATIONS

Hardware:
- Compact board (115 × 68 mm)
- Powerful 80C535 microcontroller
- 32 KByte CMOS static RAM
- 32 KByte EPROM
- RS232 interface
- All CPU port and control lines accessible via connectors
- External on/off control for on-board EPROM and RAM

Software:
- Compatible with 8051 assembler EASM51
- Compatible with 8051 system monitor EMON51
- Capable of stand alone RS232 operation
- Assembler course follow-up

tures are the subject of a short course on 80C535 hardware and software to be started in next month's issue of this magazine.

Lots of port lines

The circuit diagram of the 80C535 computer, **Fig. 1**, is basically a standard application of the 80C535 microcontroller. All port and control lines of the microcontroller, IC_6, are taken out to pins on connectors K_1 through K_8. To avoid confusion between the pin numbers and their actual positions, **Fig. 2** shows the pin arrangement of a 10-way boxheader as used on the board.

The circuit is **only** suitable for the CMOS SAB80**C**535 microcontroller, **not** for the standard N-MOS version 80535, which will be damaged 'beyond repair' when fitted because it has different functions for pins 4 and 37. Don't do it!

The address latch is formed by IC_4, a 74HC573, whose outputs supply the eight lower-order address bits A0 through A7, which are externally accessible via connector K_1. The read-only and read/write memory areas on the board are realized by a 32-KByte EPROM, IC_3, and a 32-KByte CMOS RAM, IC_1, respectively. The address decoding may strike you as unusual. A simple address decoder based on a four-fold NAND Type 74HC00 is used to divide the memory into four segments of 16 KByte each. Just like all processors in the 8051 series, the 80C535 is capable of addressing 64 KBytes of program memory (also

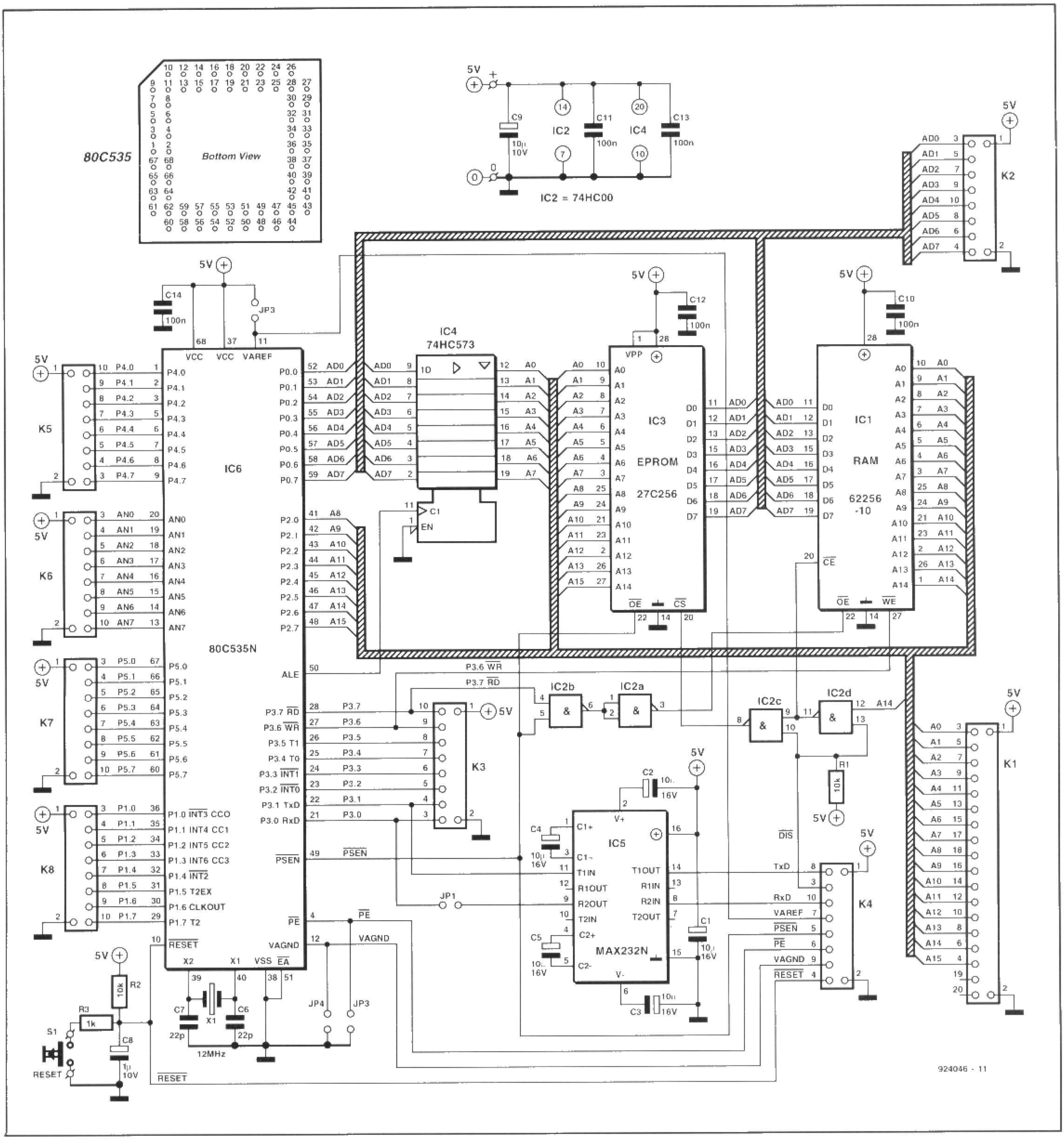


Fig. 1. Circuit diagram of the 80C535 computer.

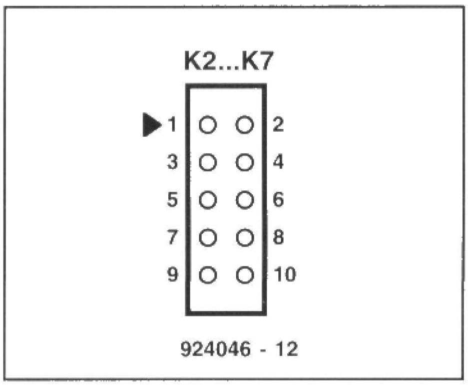


Fig. 2. Pin locations on the 10-way boxheaders used to hook up extension circuits to the 80C535 board.

called 'code' memory) **and** 64 Kbytes of data memory (also called 'external memory'). Access to the code memory is signalled by a low level on the PSEN line, while access to the data memory is marked by either $\overline{RD}$ or $\overline{WR}$ going low. The combination of logic signals in IC_2 results in a physical address assignment as given in **Table 1**. This particular memory division was chosen to allow the EMON51 system monitor EPROM (Ref. 1) to be used without problems. EMON51 expects RAM from address 4000_H onwards.

The RAM and EPROM ICs on the board may be disabled by applying a low level to the DIS pin on connector K_4. If this pin is not connected, the 80C535 uses the on-board EPROM and RAM. The on/off control over the on-board memory is provided to enable the computer to be equipped with an external EEPROM, or a RAM with battery back-up. Alternatively, this feature may be used when controlling memory-mapped input/output devices.

To make sure that the RS232 interface works with all PCs, the 80C535 board contains the well-known MAX232 RS232 serial line driver/receiver with an on-chip symmetrical voltage converter.

The microcontroller operates at a clock of 12 MHz to make sure that it can run all time-critical programs contained in the 8051 assembler language course.

Although the power-on RESET signal furnished by R_2, R_3 and C_8 will be perfectly adequate for many extension and application circuits connected to the 80C535 computer, there may be applications, such as systems with a battery-backup RAM, where the timing of the reset signal is unsuitable. In these cases, it is suggested to omit C_8 and R_2, and have the reset signal generated by a special IC with a watchdog, for example, the MAX690. If used, the external reset controller is connected to pin 4 of K_4.

Jumpers

The board contains four jumpers, whose function is discussed below.

Jumper JP_1 allows the input of the serial interface contained in the 80C535 to be connected to the output of driver IC_5. Obviously, this jumper has to be fitted if you want to communicate with the board via RS232 using the V24 program download utility on your PC. The jumper is omitted only if the board is connected to a computer or terminal which supplies TTL (0/5 V) signals, which are then fed directly to the P3.0 (RxD) input of the microprocessor. This line is also accessible

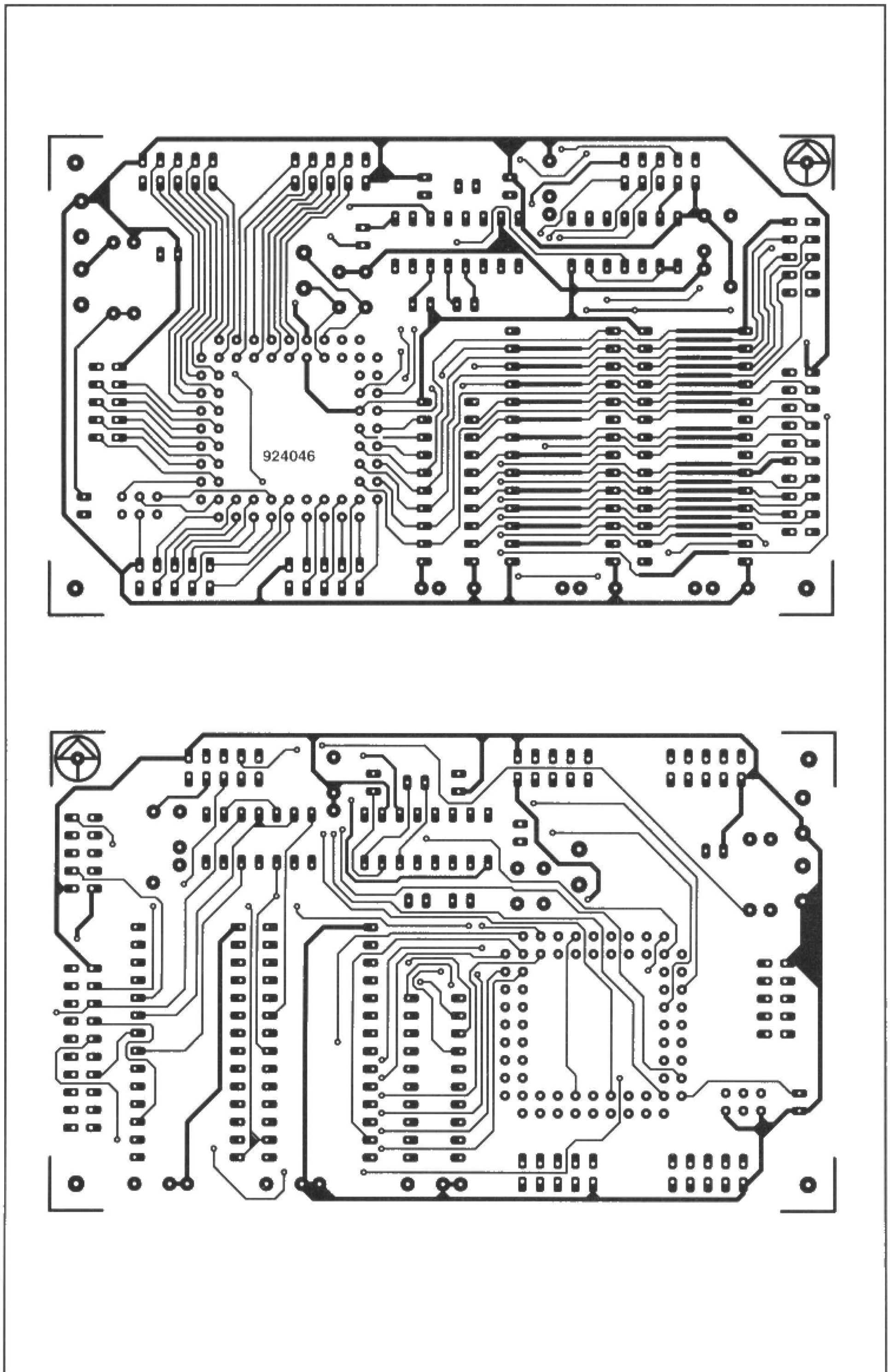


Fig. 3a. Track layouts of the double-sided through-plated printed circuit board.

Code memory access:	
0000H - 3FFFH	EPROM 0000H - 3FFFH
4000H - 7FFFH	RAM 0000H - 3FFFH
8000H - BFFFH	EPROM 4000H - 7FFFH
C000H - FFFFH	RAM 4000H - 7FFFH
Data memory access:	
0000H - 3FFFH	—
4000H - 7FFFH	RAM 0000H - 3FFFH
8000H - BFFFH	—
C000H - FFFFH	RAM 4000H - 7FFFH

Table 1. EPROM/RAM memory division.

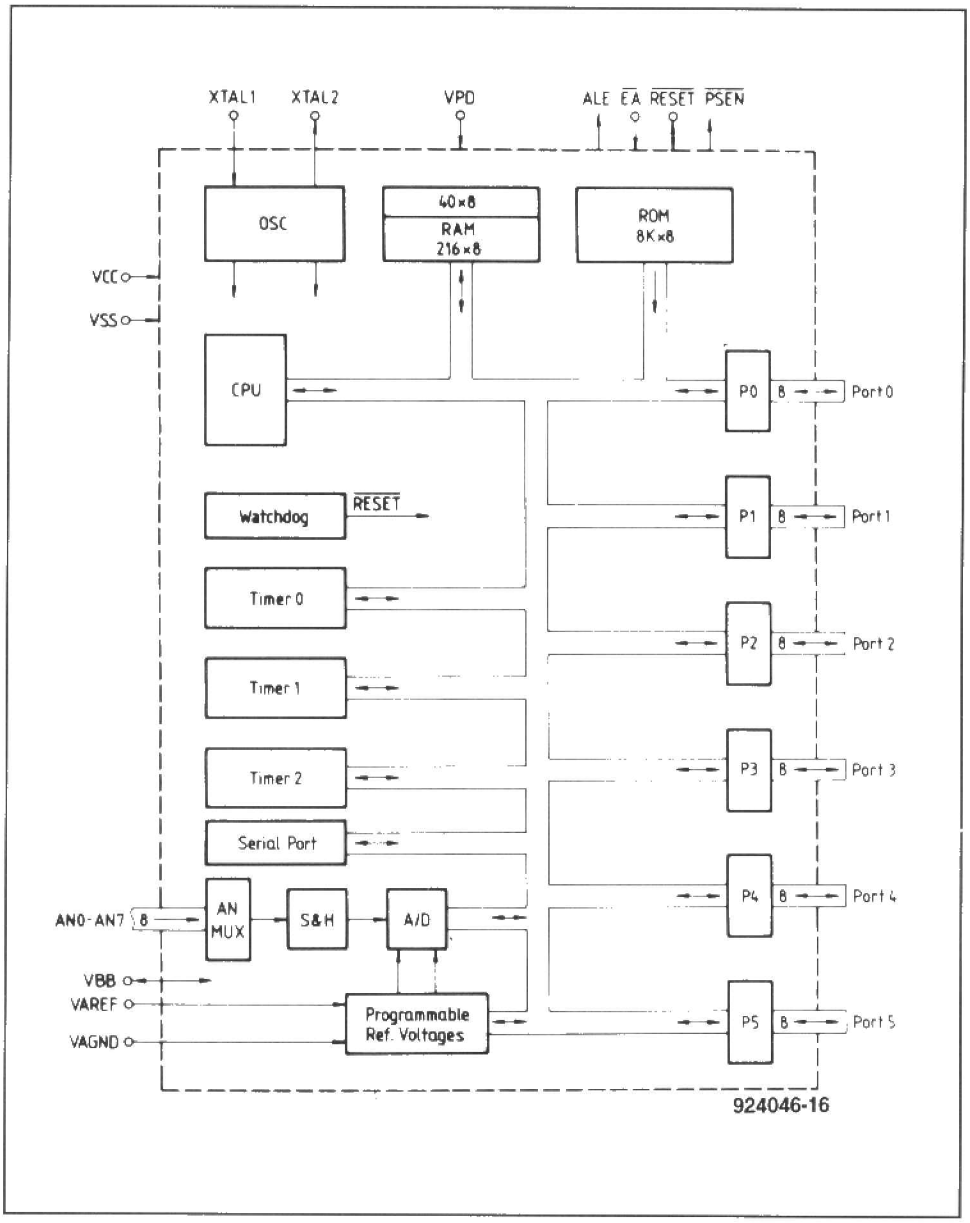


Fig. 4. SAB80C535 internal architecture (courtesy Siemens Components).

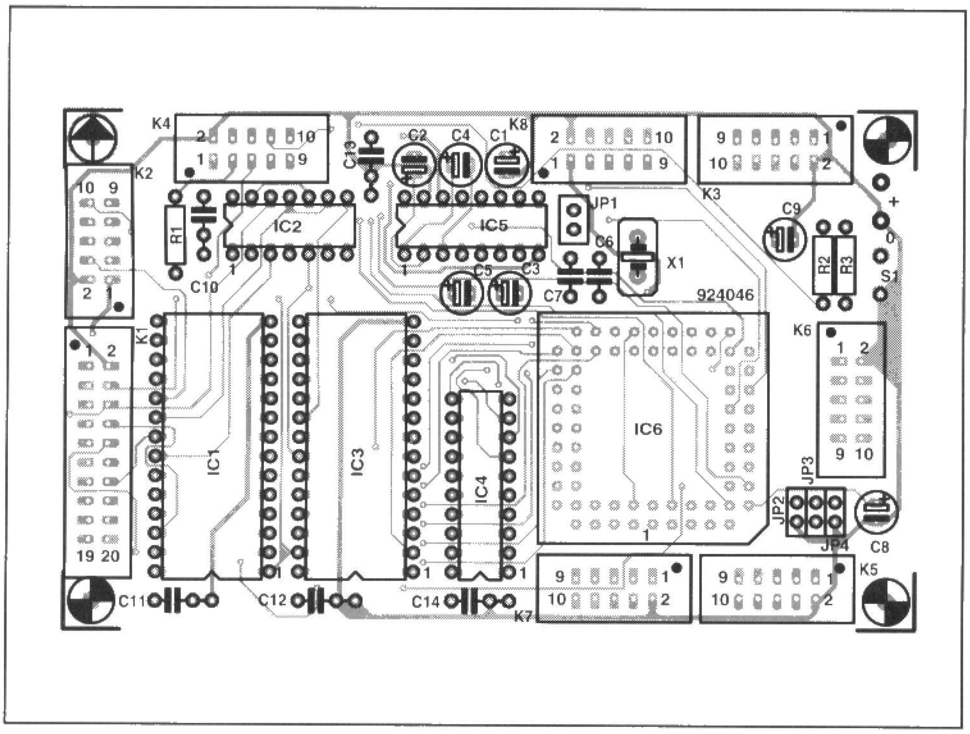


Fig. 3b. Component mounting plan.

80C535 HIGHLIGHTS

8051 software compatible
256-byte RAM
Three 16-bit timers
Eight analogue inputs
A-D converter with 8-bit resolution (10-bit via software)
Baudrate generator for 4,800 or 9,600 baud at 12 MHz clock
Four 12-bit capture/compare registers
12 interrupts with four priority levels
Watchdog timer
Two extra 8-bit I/O ports
Power-down and idle modes

via pin 3 of connector K_3.

The ADC contained in the 80C535 must be provided with a reference voltage, for which the VAREF and VAGND pins are available on the processor. If jumpers JP_3 and JP_4 are fitted, the reference is formed by the 5-V supply voltage, which will be sufficiently accurate for most simple applications. For measurements that require 'the last bit of digital precision' to be squeezed out it is recommended to use an external reference source. If this is used, omit jumpers JP_3 and JP_4, and connect the external reference to pins 7 and 9 on connector K_4. As a matter of course, stay within the limits specified

COMPONENTS LIST

Resistors:
R1;R2 = 10kΩ
R3 = 1kΩ

Capacitors:
C1-C5 = 10µF 16V radial
C6;C7 = 22pF
C8 = 1µF 10V radial
C9 = 10µF 10V radial
C10-C14 = 100nF

Semiconductors:
IC1 = 62256-10
IC2 = 74HC00
IC3 = 27C256 (EMON51 EPROM, order code 1661; see page 70)
IC4 = 74HC573
IC5 = MAX232N (Maxim Inc.)
IC6 = SAB80C535 (Siemens Components)

Miscellaneous:
K1 = 20-way boxheader
K2-K8 = 10-way boxheader
S1 = press-key, make contact
X1 = 12MHz quartz crystal
Printed circuit board 924046 (see page 70)

Jumper	Jumper fitted	Jumper not fitted
JP1	V24 to 80C535 RxD	external TTL RxD signal via K3 pin 3
JP2	Powerdown enabled	external, HIGH: Powerdown not allowed
JP3	VAREF to +5V	external reference via K3 pin 7
JP4	VAGND to GND	external analogue ground via K3 pin 9

Table 2. Jumper functions.

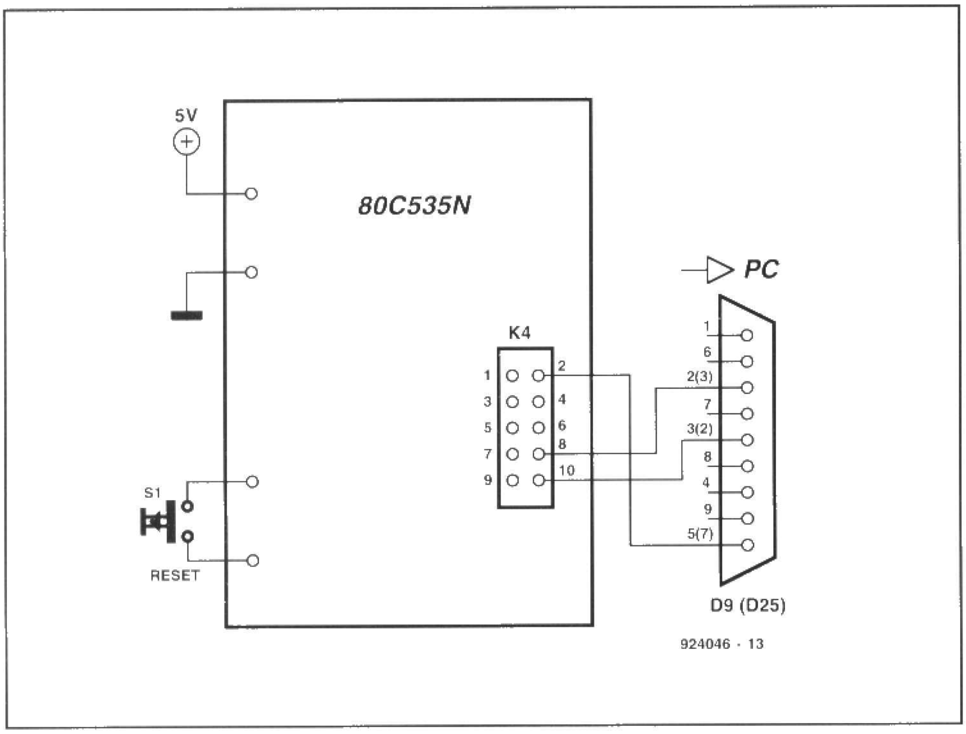


Fig. 5. Serial interface connection to the PC's RS232 port.

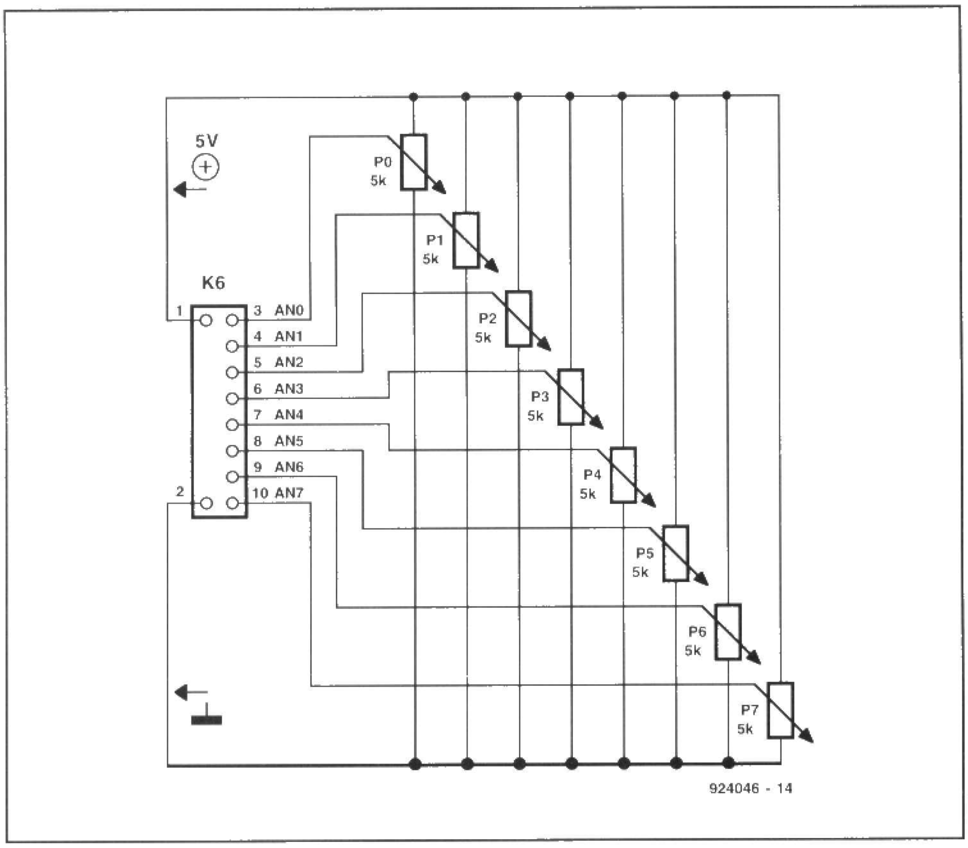


Fig. 6. Eight analogue voltages connected to the computer's analogue inputs, P0 through P7. Turn the pots to check out the operation of the test program given in Fig. 7.

for the external reference voltage. VAREF, for instance, must be within 5% of the supply voltage, while VAGND may not deviate more than 0.2 V from the ground potential. Also, the analogue input signal levels may not exceed the limits set by VAGND and VAREF by more than 0.2 V. This restriction is necessary to avoid excessive currents flowing in the input lines. In most cases, VAGND is best connected to the analogue ground of the external equipment, which is connected to the digital ground at a suitable point. VAREF is connected to the positive terminal of the external voltage source used.

Jumper JP_2, finally, controls the power-down and idle modes of the microcontroller. If JP_2 is fitted, the $\overline{PE}$ input of the 80C535 is held low, which means that the power-down and idle modes may be controlled via software. This feature is effectively disabled if JP_2 is not fitted. Disabling the software power-down and idle modes may be required in no-break systems where the clock and timer must run at all times.

The jumper functions are summarized in **Table 2**.

Construction

The artwork for the printed circuit board is given in **Fig. 3**. The board is double-sided, through-plated, and available ready-made through the Readers Services. As you can see from the component overlay, the board is pretty densely populated, so take your time fitting the components, and solder **very** accurately using a low-power solder iron with a fine tip. It is recommended to use good quality IC sockets.

If it is intended to fit the controller board on to another board, the box-headers may be replaced by double-row pinheaders fitted at the solder side.

As already mentioned, C_8 and R_2 must be omitted if an external reset controller is used.

Compatible!

You can start working with the 80C535 board straight away if you have the EMON51 monitor EPROM fitted in position IC_3. The link with the RS232 port on the PC is shown schematically in **Fig. 5**. The pin numbers in brackets refer to a 25-way sub-D connector. All jumpers are fitted on the 80C535 computer board.

First start V24 on the PC, then apply power to the 80C535 board. The system monitor should report with the welcome message on the PC after pressing reset key S_1. If not, you have a faultfinding session ahead of you. Pin 50 of the 80C535 should supply a

```
****** EASM52 ASSEMBLER LISTING (B535P1) ******
LINE LOC  OBJ         T          SOURCE
     0000                  ;  8-channel A-D converter via V24
     0000                  ;
     0000                  ;  define 80535 SFRs
     0000                  ;
     0000                  ACC    EQU 0E0H
     0000                  DPL    EQU 082H
     0000                  DPH    EQU 083H
     0000                  ADCON  EQU 0D8H
     0000                  ADDAT  EQU 0D9H
     0000                  DAPR   EQU 0DAH
     0000                  ;
     0000                  ;  Calibration constants
     0000                  p1       EQU    5000      ; counter for calibration factor
     0000                  q1       EQU    256       ; nominator of calibration factor
     0000                  ;
     0000                  ;  define internal RAM
     0000                  ;
     0000                         ORG    050H        ; start address in internal RAM
     0050                  ADval  DS      2          ; 16 Bit measured AD_value
     0052                  p      DS      2          ; p=p1 : multiplier (16 bit value)
     0054                  q      DS      2          ; q=q1 : divisor (16 bit value)
     0056                  PROD32 DS      4          ; product ADval*p (32 bit value)
     005A                  Uval   DS      2          ; result in mV=ADval*5000/256 (16 bit value)
     005C                  ;
     005C                         ORG    4100H               ; program starts at 4100H
     4100 90 41 69 [2] MAIN   MOV    DPTR,#TXT0          ; start report
     4103 31 89    [2]        ACALL  STXT                ; transmit
     4105 75 30 10 [2] MLP    MOV    COMMAND,#ccGETC     ; wait for ASCII Character
     4108 12 02 00 [2]        LCALL  MON
     410B 54 07    [1]        ANL    A,#7                ; extract channel number
     410D 44 10    [1]        ORL    A,#00010000B        ; set start ADC bit
     410F F5 D8    [1]        MOV    ADCON,A             ; set AD control
     4111 75 DA 00 [2]        MOV    DAPR,#0             ; start AD conversion from 0 to 5 Volt
     4114 20 DC FD [2] BSY    JB     ADCON.4,BSY         ; wait until ready
     4117 E5 D9    [1]        MOV    A,ADDAT             ; fetch result
     4119 F5 50    [1]        MOV    ADval+0,A           ; store as 16 bit number
     411B 75 51 00 [2]        MOV    ADval+1,#0
     411E 90 13 88 [2] OUTPUT MOV     DPTR,#p1           ; do output now
     4121 85 82 52 [2]        MOV     p+0,DPL            ; p:=p1 (16 bit value)
     4124 85 83 53 [2]        MOV     p+1,DPH
     4127 78 52    [1]        MOV     R0,#p
     4129 79 50    [1]        MOV     R1,#ADval
     412B 75 30 52 [2]        MOV     COMMAND,#ccMUL     ; compute ADval*p
     412E 12 02 00 [2]        LCALL   MON
     4131 86 56    [2]        MOV     PROD32+0,@R0       ; save to PROD32 (32 bit value)
     4133 08       [1]        INC     R0
     4134 86 57    [2]        MOV     PROD32+1,@R0
     4136 08       [1]        INC     R0
     4137 86 58    [2]        MOV     PROD32+2,@R0
     4139 08       [1]        INC     R0
     413A 86 59    [2]        MOV     PROD32+3,@R0
     413C 90 01 00 [2]        MOV     DPTR,#q1           ; q:=q1
     413F 85 82 54 [2]        MOV     q+0,DPL
     4142 85 83 55 [2]        MOV     q+1,DPH
     4145 78 56    [1]        MOV     R0,#PROD32
     4147 79 54    [1]        MOV     R1,#q
     4149 75 30 53 [2]        MOV     COMMAND,#ccDIV     ; compute (ADval*p)/q  (16 bit value)
     414C 12 02 00 [2]        LCALL   MON
     414F 86 5A    [2]        MOV     Uval+0,@R0         ; store to Uval
     4151 08       [1]        INC     R0
     4152 86 5B    [2]        MOV     Uval+1,@R0
     4154 90 41 80 [2]        MOV     DPTR,#TXT1         ; transmit text
     4157 31 89    [2]        ACALL   STXT
     4159 78 5A    [1]        MOV     R0,#Uval
     415B 75 30 05 [2]        MOV     COMMAND,#ccdRO16; output Uval in mV decimal
     415E 12 02 00 [2]        LCALL   MON
     4161 90 41 83 [2]        MOV     DPTR,#TXT2         ; transmit text
     4164 31 89    [2]        ACALL   STXT
     4166 02 41 05 [2]        LJMP    MLP
     4169                 ;
     4169 0D 0A 38        TXT0    DB 13,10,'80C535 PROGRAM #1 ',13,10,0
          30 43 35
          33 35 20
          50 52 4F
          47 52 41
          4D 20 23
          31 20 0D
          0A 00
     4180 55 3D 00        TXT1    DB      'U=',0
     4183 20 6D 56        TXT2    DB      ' mV',13,10,0
          0D 0A 00
     4189                 ;
     4189                 ; Function codes for MONITOR calls
     4189
     4189                 ccSTXT  EQU   002H                ; transmit text
     4189                 ccdRO16 EQU   005H                ; transmit 16 bit value @R0 decimal
     4189                 ccGETC  EQU   010H                ; fetch ASCII character from V24
     4189                 ccMUL   EQU   052H
     4189                 ccDIV   EQU   053H
     4189                 ;
     4189                 COMMAND EQU   030H                ; MONITOR command storage location
     4189                 MON     EQU   0200H               ; MONITOR entry address
     4189                 ;
     4189 75 30 02 [2] STXT   MOV COMMAND,#ccSTXT         ; set MONITOR command
     418C 02 02 00 [2]        LJMP MON                    ; jump to MONITOR
     418F                     END
********* SYMBOL TABLE (28 symbols) **********
      ACC :00E0      DPL :0082      DPH :0083    ADCON :00D8
    ADDAT :00D9     DAPR :00DA       p1 :1388       q1 :0100
    ADval :0050        p :0052        q :0054   PROD32 :0056
     Uval :005A     MAIN :4100      MLP :4105      BSY :4114
   OUTPUT :411E     TXT0 :4169     TXT1 :4180     TXT2 :4183
   ccSTXT :0002  ccdRO16 :0005   ccGETC :0010    ccMUL :0052
    ccDIV :0053  COMMAND :0030      MON :0200     STXT :4189
```

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Fig. 7. Example program that makes use of the analogue-to-digital converter contained in the 80C535 microcontroller.

clean ALE pulse, which can be verified with the aid of an oscilloscope. If you do not see a stable rectangular wave signal with TTL swing, the problem is most likely caused by a faulty or otherwise unsuitable quartz crystal. Exchange the crystal and try again.

Next, check all address and data lines for signals which do not have a TTL swing. If such a signal is found, or a more or less stable level of 2.5 V with respect to ground, you are probably faced with a pair of data or address lines which are short-circuited by excess solder.

If the monitor reports okay on the PC, you may download a chunk of object code, for instance, one of the example programs contained on the 8051 assembler course diskette. In the unlikely event of errors occurring, these are probably caused by a faulty RAM, IC_1.

All programming features of the 80C535 are supported by the 8051 assembler, EASM51, provided the 'new' special function registers of the 80C535 are properly defined using appropriate EQU statements in the assembler code.

A test application

The program listed in **Fig. 7** enables eight analogue voltages to be measured via the RS232 link with the PC. The desired channel number (between 0 and 7) is transmitted to the 80C535 board via the V24 utility (at 4,800 baud). The board returns the voltage level in decimal notation. The voltages to be measured must lie between 0 and +5 V, and are connected to boxheader K_6 (see **Fig. 6**).

The A-to-D conversion yields a digital value of 0 for an input voltage of 0 V, and 255, for an input voltage of 4.98 V. The actual signal voltage, *U*, is therefore computed from

$$U = \text{measured value} \times 5\ \text{V} / 256 \qquad \text{(V)}$$

This is done by the program, which for convenience also handles the conversion into millivolts (mV). The arithmetic and number output subroutines contained in EMON51 are used for this purpose. ■

Reference:

1. 8051/8032 assembler course, *Elektor Electronics* February through November 1992. Course disk and monitor EPROM order code: 1661 (see page 70).

Solution to the Prize Electronic Crossword 2 by Matrix (December 1993)

Across

1. Common collector
9. Renumber
10. Stereo
12. Inst
13. Die-hard
14. FM
17. Gratis
18. Anathema
21. Filament
22. Litmus
24. RF
25. Off-days
27. Ecru
30. Ampere
31. Bachelor
33. Darlington pairs

Down

1. Carriage forward
2. Monostable
3. Ohms
4. Credit
5. LA
6. Ester
7. Tera
8. Root mean squares
11. Shunt
15. Film
16. Vermicelli
19. Trim
20. Anode
23. Dynamo
26. Fermi
28. Spar
29. Chip
32. MG

Winners of the construction kits are:

1st prize: P.B. Pinnell

2nd prize: S. Lewondowski

3rd/4th/5th prizes:
N.L. Cunningham
P.S. Mainwaring
W. Sykes

Winners of the book prizes are:
A.C. Arnold
J. Cott
Mark Latham
Will Rimell
William Ritchie

All winners have been advised by letter.

LETTERS

Dear Editor—I know that a CGA card can relatively simply be connected to a TV receiver. Is this possible with a VGA card? I have not been able to find any literature on this.
J. Scott, Preston

The line and field frequencies used with a CGA card are similar to those used in a TV receiver, so that interfacing the two is, as you say, pretty straightforward. This is, unfortunately, not the case with a VGA card. The required interface would be quite complex. We have not published a design for this and, as far as we know, neither have other amateur publications. There are commercial units available, but these cost a couple of hundred pounds. [Editor]

Dear Editor—I would like to get some more detailed information on the 'VHF/UHF tuner' (Oct/Nov 1993) as on the enclosed sheet of paper.
S. Svenson, Stockholm

Unfortunately, neither our Design Department nor the original (free-lance) designer have the time to go into your request. They feel, however, that most of the information you seek is already contained in the article. We trust that you will appreciate that with our busy agenda of getting our magazine out on time every month it is just impossible to enter into individual correspondence on a completed project. [Editor]

Dear Editor—I work in an environment where some equipment produces a fairly high steady frequency sound. I have read somewhere about 'anti sound' apparatus. Is such equipment available or can it be built simply? I have in mind to design such a unit with a microphone at one end and a loudspeaker at the other. Can you offer any suggestions?
F. Velsink, Holland

There does exist anti-sound equipment, but this is quite complex. The complexity arises from the fact that the sound to be eliminated must be monitored and analysed constantly. The anti-sound must be generated close to the source of the offending sound by a number of powerful loudspeakers. The frequency and level of the anti-sound must be adapted constantly to ensure that the sum of all the sounds is as small as feasible.

It is, therefore, not just a question of placing a microphone near the source of the offending signal and feed back the sound in anti-phase via a couple of loudspeakers. All the time, the system must be intelligent enough to detect how and to what degree the anti-sound must be changed to further reduce the offending sound or at least to keep it at a low level.

As far we know, there are no DIY kits for this type of equipment. [Editor]

COMPONENT RATINGS

In resistor and capacitor values, decimal points and large numbers of zeros are avoided wherever possible. Small and large values are usually abbreviated as follows:

p (pico-)	$= 10^{-12}$
n (nano-)	$= 10^{-9}$
µ (micro-)	$= 10^{-6}$
m (milli-)	$= 10^{-3}$
k (kilo-)	$= 10^{3}$
M (mega-)	$= 10^{6}$
G (giga-)	$= 10^{9}$

Note that nano-farad (nF) is the international way of writing 1000 pF or 0.001 µF. Resistors are $^1/_3$ watt, 5% metal film types unless otherwise specified.

The direct working voltage of capacitors (other than electrolytic or tantalum types) is assumed to be ≥60 V. As a rule of thumb, a safe value is about 2× direct supply voltage.

Direct test voltages are measured with a 20 kΩ/V meter unless otherwise specified.

Mains (power line) voltages are not listed in the articles. It is assumed that our readers know what voltage is standard in their part of the world.

Readers in countries that use 60 Hz supplies, should note that our circuits are usually designed for 50 Hz. This will not normally cause problems, although if the mains frequency is used for synchronization, some modification may be required.

The international letter symbol '*U*' is used for voltage instead of the ambiguous '*V*'. The letter V is reserved for 'volts'.

The size of a metric bolt or screw is defined by the letter M followed by a number corresponding to the overall diameter of the thread in mm, the × sign and the length of the bolt or screw, also in mm. For instance, an M4×6 bolt has a thread diameter of 4 mm and a length of 6 mm. The overall diameter of the thread in the BA sizes is: 0 BA = 6.12 mm; 2 BA = 4.78 mm; 4 BA = 3.68 mm; 6 BA = 2.85 mm; 8 BA = 2.25 mm.